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INFLUENCE OF POLLUTION ON PHOTOSYNTHESIS PIGMENT CONTENT IN NEEDLES OF *Picea abies* AND *Picea pungens* IN CONDITIONS OF DEVELOPMENT OF IRON ORE DEPOSITS

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Abstract

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We studied photosynthetic pigments in needles of *Picea abies* and *P. pungens* in plantings exposed to aerotechnogenic influence of various levels in the big industrial center of steppe zone of Ukraine (Kryvyi Rih). We analyzed the pigment content in needles of the second year of life sampled from 30 to 40-year-old trees of both species in 6 monitoring sites for 5 months. For the needles of *P. abies* and *P. pungens* from all the sites, we noticed the decreasing content of chlorophyll *a* (to 27.2 and 25.0%, respectively) and chlorophyll *b* (to 17.9 and 20.0%, respectively) from May till September, in comparison with background territory. At the same time, the content of carotenoids performing the protective function in photosynthetic reactions increased up to 26.1 and 24.0%, respectively. For *P. abies* and *P. pungens* growing in conditions of intensive technogenic pressure, we ascertained that, during investigations, the sum of chlorophylls (*a* + *b*) rate decreased to 24.4 and 23.6%, respectively; ratio (*a*/*b*) decreased to 11.4 and 12.3%, respectively; ratio (chlorophylls [*a* + *b*]/carotenoids) also decreased to 30.1 and 38.0%, respectively, in comparison with plants from the least polluted site. It is shown that the most intensive negative influence on plantings is caused by industrial pollution and exhaust gases: the minimum or, more rarely, the maximum rates of pigment content appeared in needles of the plants exactly from these sites. Our research results demonstrate the feasibility of using the pigment complexes of *P. abies* and *P. pungens,* with the assimilative apparatus sensitive to air pollution damage, as indicators of air environmental conditions.

Key words: coniferous plants, assimilation apparatus, chlorophylls *a* and *b*, carotenoids, aeropollutants.

Introduction

Ukraine stands out from other countries in Europe and throughout the world because of its large iron deposits (54% of world reserves) (Kucherov, Ovchynnikova, 2009). During the extraction of iron ore, various types of pollutants are emitted into the atmosphere, the most common among them are dust, sulfur dioxide, carbon monoxide, hydrogen sulfide, nitrogen oxide, and others (Schwegler, 2006; Kucherov, Ovchynnikova, 2009). As a result of industrial activity, the state of environment in many industrial cities of the steppe zone of Ukraine is characterized as critical. Under such conditions, tree plantations play an important role in the system of measures for the improvement of the environment. Plants, being a reliable natural filter, clean, humidify, and enrich the air of cities with oxygen; reduce wind and noise; and change radiation and temperature (Nowak et al., 2014; Sergejchik, 2015; Bessonova, Ponomar'ova, 2017; Volodarets et al., 2018). However, they respond rapidly to the presence of even small doses of toxic substances in the air, being damaged by solid particles of industrial emissions that do not have visible effects on humans and animals. Therefore, plants are considered to be the best environmental indicators (Nowak et al., 2014; Uhrin, Supuka, 2016; Afanas'eva, 2018).

Of all the biodiversity of urban dendroflora, the species from the Pinaceae family are suggested for use as year-round bioindicators of aerotechnogenic contamination (Mosseler et al., 2001; Bessonova, Ponomar'ova, 2017; Korshikov et al., 2019), while deciduous trees, annually renewing leaves, clear up from toxic compounds (Doncheva, 1978). The assimilation apparatus in coniferous plants is a potentially reliable biomarker of the plant response to stress (Kvilala et al., 2014; Schiop et al., 2015). This point of view is proven by the studies conducted in the east of Ukraine, where representatives of the Pinaceae were introduced 30–40 years ago (Poljakov, Suslova, 2009).

Evaluation of the condition of urban plantations requires an early diagnosis of tree stand life, which allows obtaining shortly the complete information on the degree of technogenic impact on plantings. In the first place, the conifer damages manifest themselves at the physiological and biochemical levels (Starikova et al., 2016) and then extending to the ultrastructural and cellular level changes. And only afterwards, there develop visual signs of plant damage, namely, chloroses and necroses of needle tissues, needle fall, and decrease in needle length and growth of lateral shoots (Bacic et al., 2003; Pavlov 2005; Mikhailova et al., 2017). This susceptibility is explained by the fact that most important physiological processes are carried out in the assimilation apparatus, which is the center of variability or plasticity of the organism (Shubert, 1988). It is known that one of the biochemical indices of plant reaction to the change of environmental factors and adaptation degree to the new environmental conditions is the content of chlorophylls and carotenoids—the main photoreceptors of the photosynthetic cell (Di Vittorio, 2009; Verma, Chandra, 2014). The widely used indicators of needle damage caused by air pollution is the decrease in the chlorophyll content, as well as the difference in its *a* and *b* forms and carotenoid changes (Tausz et al., 1996; Lepedus et al., 2003; Bessonova et al., 2004). Many foreign and domestic authors discuss the physiology of the impact of harmful emissions from industrial enterprises (Lepedus et al., 2003; Mikhailova et al., 2017) and vehicle exhaust gases (Verma, Chandra, 2014; Bessonova, Ponomar'ova, 2017) on the pigment content in coniferous plants.

In Kryvyi Rih, with the annual industrial emissions of 358,600 tons in 2011 (Gryshko et al., 2012), such investigations should become an integral part of environmental monitoring. In this case, because of the absence of aboriginal coniferous plants, there is a need to use introduced species in the course of such investigations. Among the coniferous species commonly used in landscaping in Kryvyi Rih are *Picea abies* (L.) Karst and *P. pungens* Engelm., which grow in single, roadside, group and block plantings that facilitate using them as test systems for bioindication.

It should be noted that the earlier studies of the pigment complex of coniferous plants under conditions of high air pollution (in the Russian city of Izhevsk) characterized *P. pungens* as a more stable species compared to *P. abies* because of the increased content of chlorophyll *a* (Bukharina et al., 2016). However, a number of researchers (Soukupova et al., 2001) observed that the needles of *P. abies* and *P. pungens* have the same degree of damages in response to atmospheric air pollution and the number of pigments in the latter species, on the contrary, is smaller. Therefore, it is relevant to compare the pigment complex and its contents in both spruce species during the growing season, which will allow us to evaluate the plant reaction to the effect of technogenic pollution.

The aim of our investigation is to find out the features of the seasonal dynamics of photosynthetic pigments content in the assimilation apparatus of the species *P. abies* and *P. pungens* in plantations exposed to different levels of aerotechnogenic influence in the conditions of a large industrial city in the steppe zone.

Material and methods

The research material was the needles of the second year of life sampled from 30 to 40-year-old trees of *P. abies* and *P. pungens* during the growing season in 2017. The tree form with blue-green needles (*P. pungens* "Glauca") was investigated as the most widely used in landscaping in Kryvyi Rih and other cities of Ukraine (Bilyk, Grabovyj, 2006).

It is theoretically grounded to use for such investigations the needles of certain age: on the one hand, fully developed and stable and, on the other hand, without any signs of aging (Zarek, 2016). The specific features of the initial development period of needles sampled for analysis were determined by the weather conditions of the growing season in 2017. The air temperature in relation to the long-term average monthly figures was normal: 15.5 (May) to 24.4 °C (August). The maximum deviation of the temperature from the standard exceeded the multi-year indicators by +3.2 °C in August. The highest humidity (86%) was registered in July and the lowest (42%) in June (http://www.pogodaiklimat.ru). Dry periods alternated with rain. There were no climatic anomalies substantially changing the initial proportions of the individual component contents in the pigment complex.

The 6 main monitoring plantations are concentrated in two districts of the city: Metallurgical and Ternivsky (Fig. 1). Two of them are relatively weakly exposed to air pollution: the first was located in the Arboretum of the Kryvyi Rih Botanical Garden of the National Academy of Sciences of Ukraine, henceforward referred to as KBG (Section 1, control), and the second was located in Antiterrorist Operation Heroes' Park (Section 2). The next two are the roadside stands along Cherkasova Street (Section 3) and especially heavily trafficked Metallurgists' Avenue (Section 4), where the number of cars in 1 hour is 3 times greater than that in the Cherkasova Street. The highest concentrations of aerotechnogenic emissions are observed at Section 5 near the Private JSC 'North Ore Dressing Combine' (henceforward referred to as Northern GOK) and Section 6 near the metallurgical giant Public JSC "ArcelorMittal Kryviy Rih".

In each monitoring site, a total of 10 samples were collected from 7 trees of *P. abies* and *P. pungens*. In order to determine the content of pigments, an average sample was replicated for five times: 2 mL of dimethyl sulfoxide (DMSO) was added to 0.1 g of the fragmented plant material and incubated in water bath at a temperature of 67 °C for 3 hours. In the resulting extract, measurements were made using a spectrophotometer SF–2000 at a wavelength of 665 and 649 μm for chlorophylls *a* and *b,* respectively, and 480 μm for carotenoids. The pigment content follows the following expressions:

$C_a = 12.19 \times A\ 665 - 3.45 \times A\ 649;$

$C_b = 21.99 \times A\ 649 - 5.32 \times A\ 665;$

$S_{car} = (1000 \times A\ 480 - 2.14 \times Ca - 70.16 \times Cb)/220,$

where C is the concentration of pigments, mg/mL (Wellburn, 1994).

Statistical analysis was performed using Microsoft Office Excel 2003. To compare two independent samples, we used Student's *t*-criterion ($p \leq 0.05$).

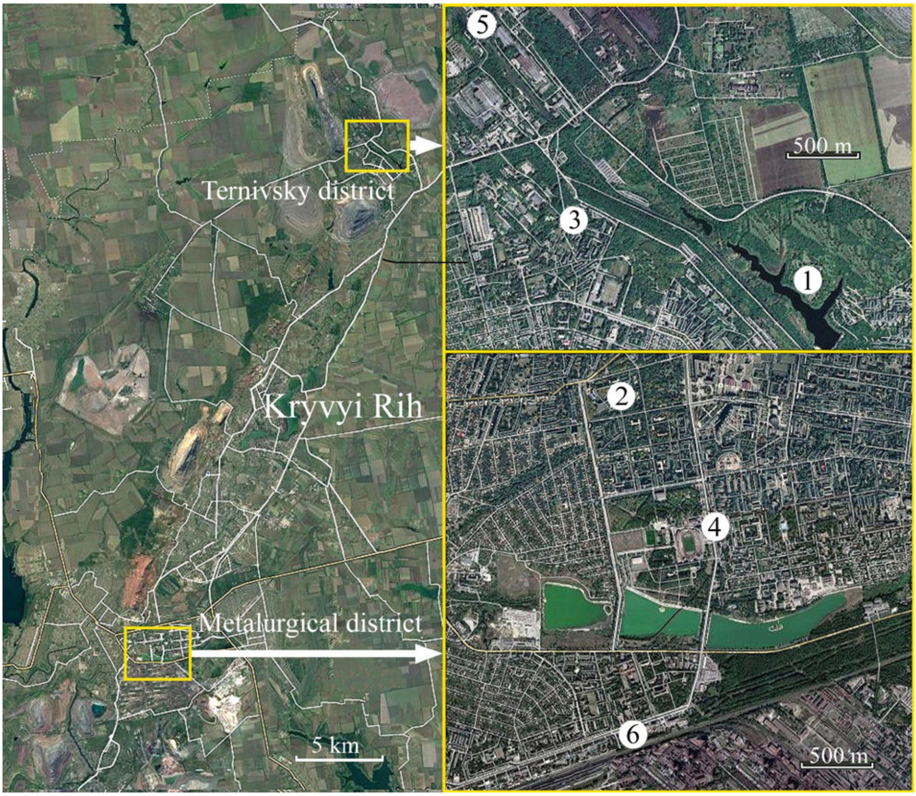

Fig. 1. Satellite data of the northern and central parts of Kryvyi Rih (available from https://www.google.com/maps). Notes: 1 – 48°08'47.3"N 33°34'51.9"E; 2 – 47°54'13.9"N 33°23'20.4"E; 3 – 48°09'27.9"N 33°33'13.2"E; 4 – 47°53'46.6"N 33°23'41.6"E; 5 – 48°09'33.1"N 33°33'12.4"E; 6 – 47°53'05.1"N 33°23'33.5"E – monitoring sites.

Results

For early manifestations of the plant stress condition induced by pollution at the physiological and biochemical levels, the contents of chlorophyll *a* and *b* content, which are sensitive to the activity of air pollutants, are most often used as indicators.

The maximum content of chlorophyll *a* in the needles of *P. abies* and *P. pungens* was fixed in May (1.04 and 1.24 mg/g of wet weight, respectively) in a relatively "clean" area (control) (Fig. 2), which was higher, on an average, by 16.3 and 20.6%, respectively, than that of plants from industrial sites. Somewhat smaller differences were observed in the trees of *P. abies* and *P. pungens* in roadside stands; the values were lower, on an average, by 14.4 and 14.9% compared with those in the KBG.

The lowest chlorophyll content in *P. abies* and *P. pungens* was recorded at ArcelorMittal Kryviy Rih site in September (0.58 and 0.70 mg/g wet weight, respectively), which is lower by 21.6 and 29.3%, respectively, compared to plants from the Botanical Garden. For both

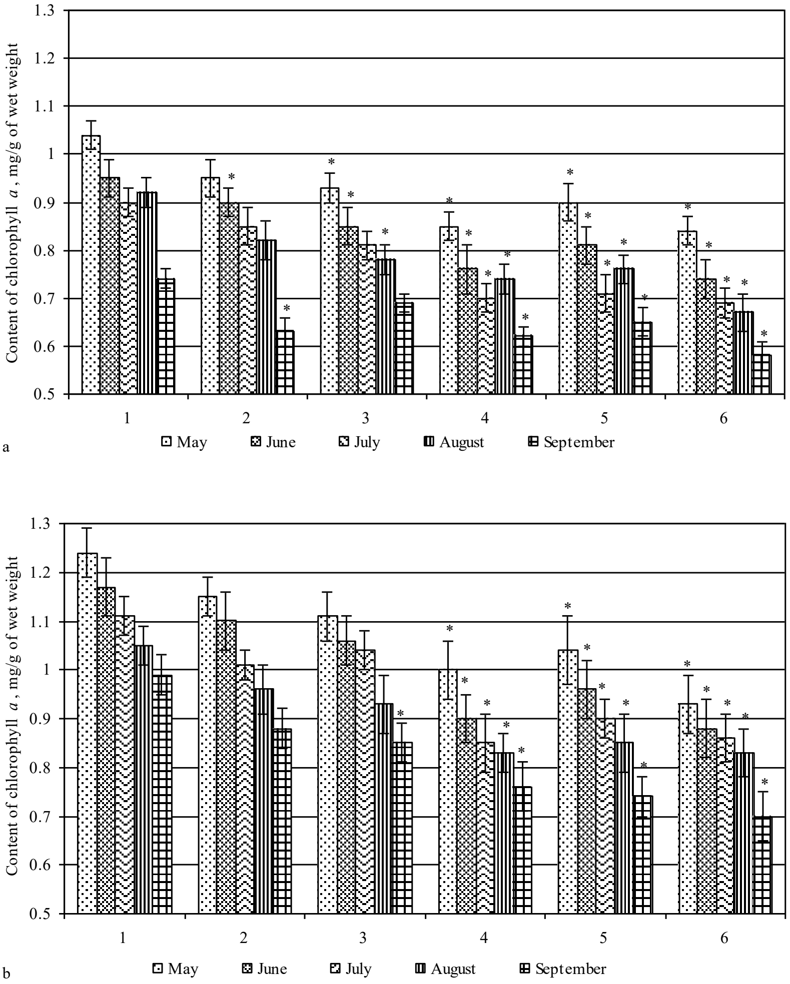

Fig. 2. Quantitative content of chlorophyll *a*, mg/g of wet weight, in the species of *Picea abies* (a) and *Picea pungens* (b) from different plantations of Kryvyi Rih (Sections 1–6; n = 5; * represents that the values are significantly different from the control at p≤0.05).

species, we observed a general tendency to reduce this pigment during summer and autumn, especially in September, as this period was characterized by low rainfall and air drought. In the course of 5-month studies, a significant decline in the chlorophyll *a* in both tree species in roadside stands and industrial sites was observed, especially in *P. abies*. In the needles of *P. pungens* in the urban plantations, the content of chlorophyll *a* was relatively stability as well as its concentration was higher than that in *P. abies*, which is more sensitive to technogenic influence.

The maximum accumulation of chlorophyll *b* in *P. abies* and *P. pungens* was observed in May in KBG (0.41 and 0.50 mg/g of wet weight, respectively), which is higher, on an average,

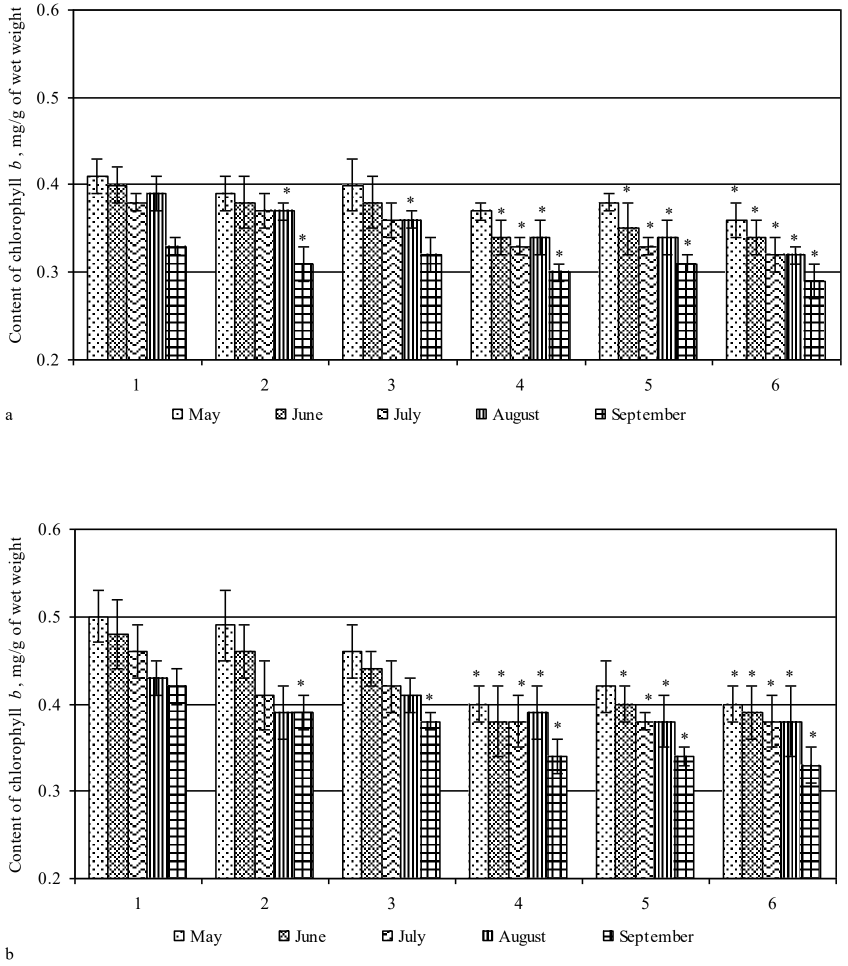

Fig. 3. Quantitative content of chlorophyll *b*, mg/g of wet weight, in the species of *Picea abies* (a) and *Picea pungens* (b) from different plantations of Kryvyi Rih (Sections 1–6; n = 5; * represents that the values are significantly different from the control at $p \leq 0.05$).

by 9.8 and 18.0%, respectively, when compared to trees growing near industrial enterprises and by 6.1 and 14.0%, respectively, when compared to those for roadside stands (Fig. 3).

The content of chlorophyll *b* was found to be minimal in the needles of *P. abies* and *P. pungens* in September at the ArcelorMittal Kryviy Rih site (0.29 and 0.33 mg/g of wet weight, respectively), which is lesser by 14.7 and 21.4%, respectively, less compared to the plants of the Botanical Garden. During the 5 months of investigations, there was an insignificant increase in the chlorophyll *b* in the stands of both spruce species with the distance from roads and industrial emissions of ore mining and processing enterprises and also from metallurgical combines.

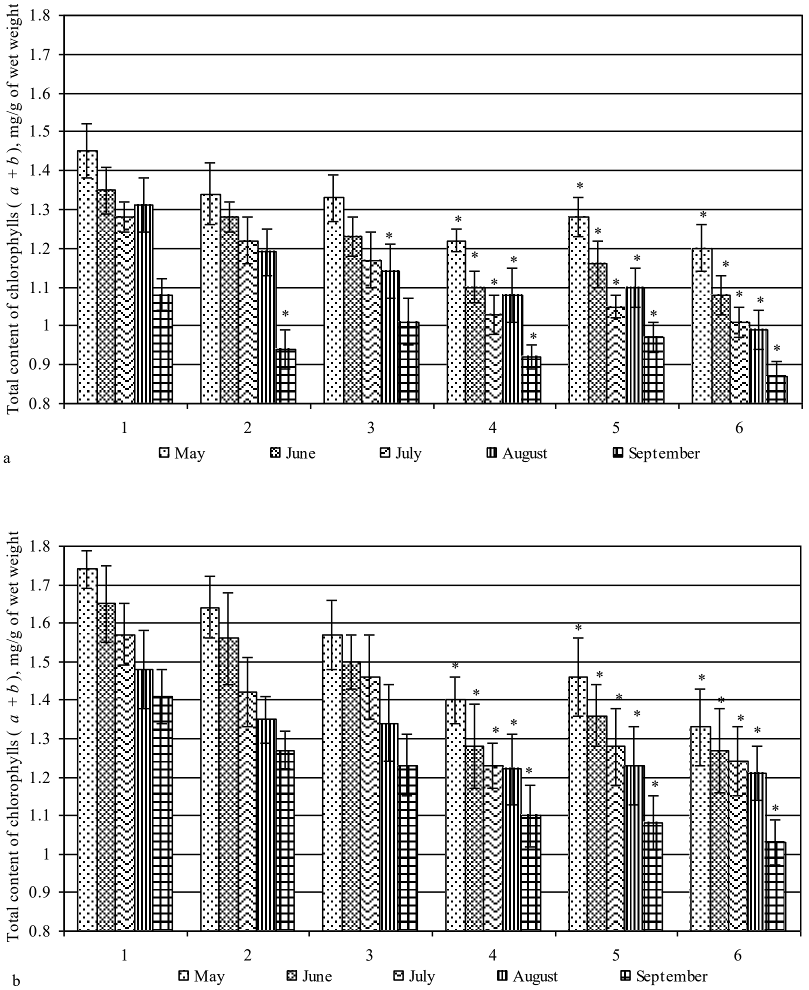

Fig. 4. Total content of chlorophylls (*a* + *b*), mg/g of wet weight, in the species of *Picea abies* (a) and *Picea pungens* (b) from different plantations of Kryvyi Rih (Sections 1–6; n = 5; * represents that the values are significantly different from the control at $p \leq 0.05$).

The highest values of the sum of chlorophylls (*a* + *b*) in plants of the genus *Picea* were observed in May (Fig. 4). The maximum indices for all the six plantations were recorded in this period in the needles of *P. abies* (1.45 mg/g of wet weight) and *P. pungens* (1.74 mg/g of wet weight) in the KBG, which is higher, on an average, by 14.5 and 19.8% when compared to the trees from industrial sites. The largest number of chlorophylls in the needles of both species in May is due to the beginning of vegetation, sufficient rainfall, and not very hot weather compared with the following months. When comparing the sum of chlorophylls (*a* +

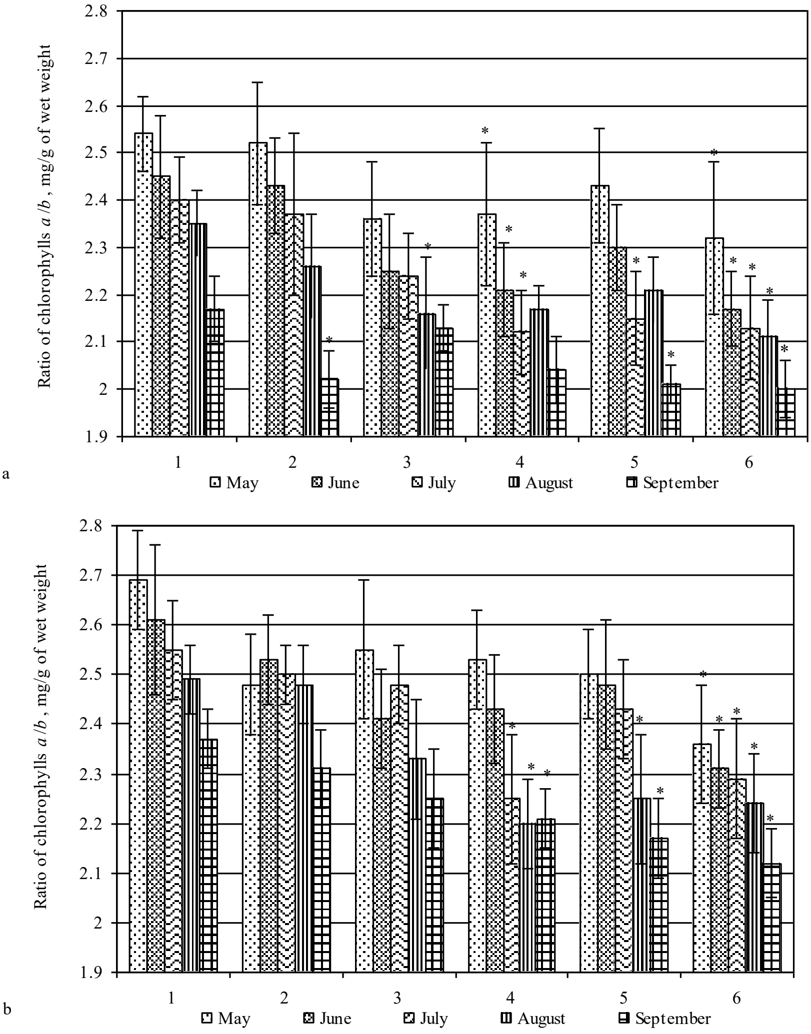

Fig. 5. Ratio of chlorophylls (*a/b*), mg/g of wet weight, in the species of *Picea abies* (a) and *Picea pungens* (b) from different plantations of Kryvyi Rih (Sections 1–6; n = 5; * represents that the values are significantly different from the control at p≤0.05).

b) between these species in May in plantations of the KBG, it was observed that in *P. pungens*, this figure was greater by 16.7% when compared to *P. abies*. Within 5 months, a decrease in the sum of chlorophylls (*a* + *b*) in plants of both species of the *Picea* genus was observed in all monitoring sites, but the values significantly differed from control in trees from industrial sites, less frequently along highways.

It was revealed that the lowest values of the sum of chlorophylls for 5 months were characteristic of pigment complexes of both tree species in plantations from the metallurgical region (40 km south of the KBG of the National Academy of Sciences of Ukraine). In plants of *P. abies* and *P. pungens* near ArcelorMittal Kryvyi Rih, in the last month of the growing season, the sum of chlorophylls was 0.87 and 1.03 mg/g of wet weight, respectively, which was significantly lower by 19.4 and 27.0% compared to the trees of the Botanical Garden. In the plantations along the Metallurgists Avenue, the sum of pigments in the needles of both spruce species was lower by 8.9 and 10.7%, respectively, compared with similar indicators of trees from roadside planting in Cherkasova Street. This trend was also observed in the ATO Heroes' Park, where the values were smaller compared with the trees of the Botanical Garden but not statistically reliable. Obviously, the transport exhaust gases and the emissions from ArcelorMittal Kryviy Rih metallurgical plant negatively affected the content of photosynthetic pigments. The impact of climatic factors such as air temperature and rainfall, which depend on the geographical location, is also significant. Less amount of atmospheric precipitation in the southern regions of the city causes a retarded development of the assimilation apparatus, reflected in the number of pigments.

The content of chlorophylls (*a/b*) is one of the informative parameters that are characteristic of the photosynthetic apparatus function. Depending on the increase in the proportion of chlorophyll *a* in this ratio, the process of photosynthesis is activated. The highest values of chlorophyll ratio (*a/b*) in the needles of *P. abies* (2.54 mg/g of wet weight) and *P. pungens* (2.69 mg/g of wet weight) were found in the trees from the Botanical Garden in May and were higher, than in other investigated plantations, during the growing season (Fig. 5).

The smallest ratio of chlorophylls (*a/b*) was observed in the needles of *P. abies* and *P. pungens* in September (2.0 and 2.12 mg/g of wet weight, respectively) near ArcelorMittal Kryviy Rih, which is less by 7.8 and 10.5%, respectively, compared to the trees from the KBG. The similar data for both species were observed during 5 months near the Metallurgists Avenue; that can be explained by the excessive impact of exhaust gases and the industrial emissions in the Metallurgical District.

Carotenoids are compulsory components of the plant pigment system. Their number in the needles of both species from the genus *Picea* for 5 months changed from 0.20 to 0.34 mg/g of wet weight; the concentration increased in line with the increase in the pollution level (Fig. 6). Thus, their highest content of 0.32 and 0.34 mg/g of wet weight was detected in the needles of *P. abies* and *P. pungens*, respectively, in September at ArcelorMittal Kryviy Rih site, which is more by 18.5 and 21.4%, respectively, compared to the trees from KBG. Values close to these were observed in the trees of both species from the site near PJSC "Northern-GOK" and along highways, indicating their protective reaction to atmospheric air pollutants.

The smallest amount of carotenoids in the needles of *P. abies* and *P. pungens* was recorded in all monitoring plots in May, especially in the trees from KBG (0.20 and 0.22 mg/g of wet weight, respectively). For 5 months, there were no significant differences in the carotenoid content in the species of the genus *Picea* from different investigated sites.

The ratio of the sum of chlorophylls to the concentration of carotenoids plays an important role in the work of the photosynthetic apparatus. This indicator reflects the reaction of sensitivity in coniferous plants to various changes in the environment. The minimum values

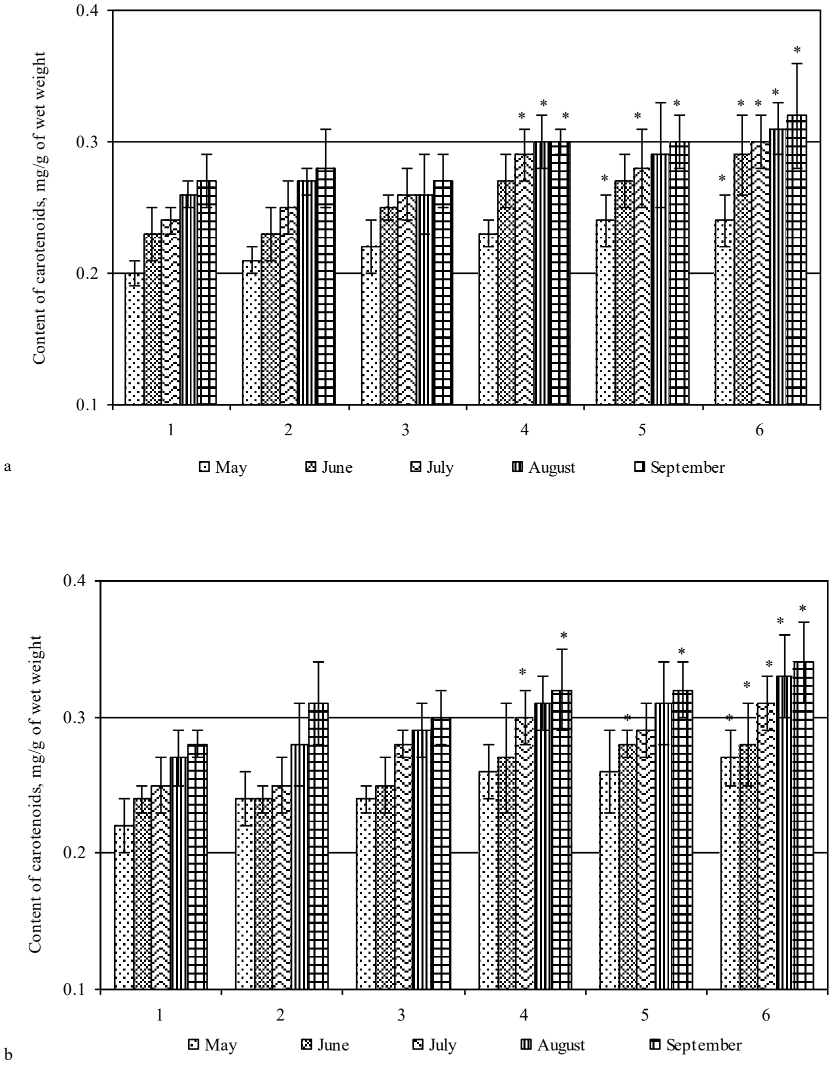

Fig. 6. Quantitative content of carotenoids, mg/g of wet weight, in the species of *Picea abies* (a) and *Picea pungens* (b) from different plantations of Kryvyi Rih (Sections 1–6; n = 5; * represents that the values are significantly different from the control at p≤0.05).

(2.74 and 3.04 mg/g of wet weight, respectively) in the needles of *P. abies* and *P. pungens* trees were recorded in September at ArcelorMittal Kryviy Rih site, which is less by 30.6 and 40.3%, respectively, compared to the trees from the Botanical Garden (Fig. 7).

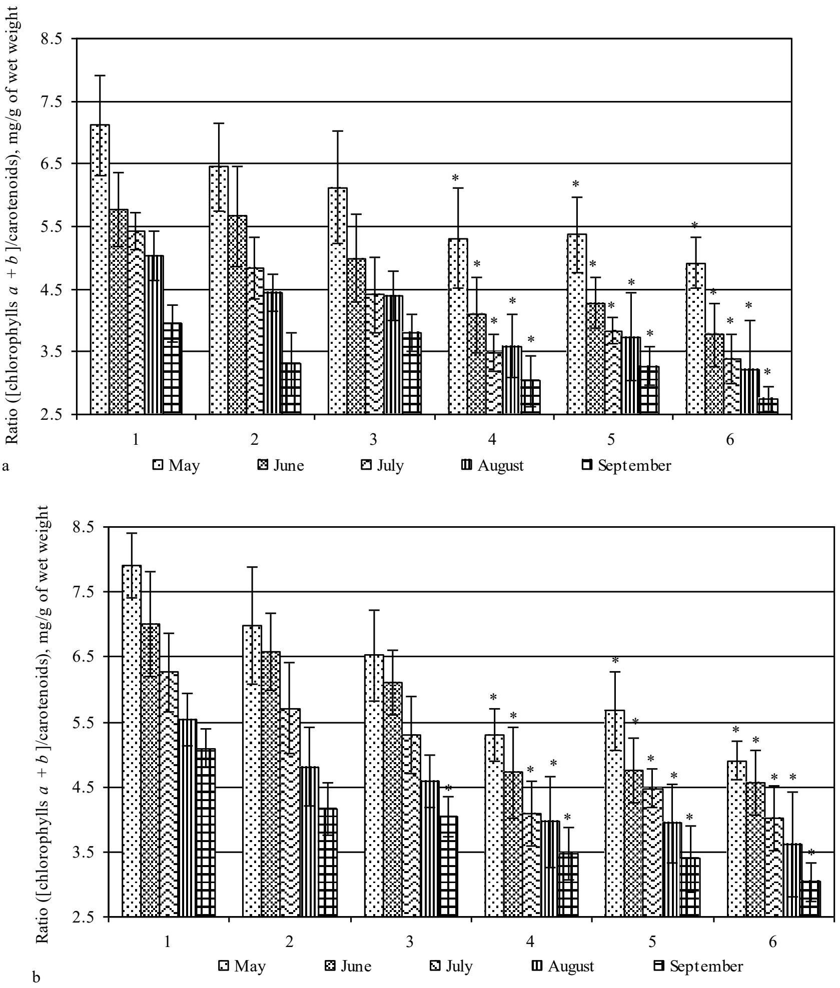

Fig. 7. Ratio ([chlorophylls *a* + *b*]/carotenoids), mg/g of wet weight, in the species of *Picea abies* (a) and *Picea pungens* (b) from different plantations of Kryvyi Rih (Sections 1–6; n = 5; * represents that the values are significantly different from the control at $p \leq 0.05$).

The reduced value of this ratio indicates deterioration of the photosynthetic activity in trees under conditions of atmospheric air pollution. The greater is the distance between *Picea* plantations and the sources of industrial emissions, the higher is the ratio ([chlorophylls *a* + *b*]/carotenoids) in spruce needles. The maximum value of the ratio ([chlorophylls *a* + *b*]/carotenoids) was detected in May (7.12 and 7.90 mg/g of wet weight, respectively) in the needles of *P. abies* and *P. pungens* trees growing in the KBG. These values are higher, on an average, by 27.7 and 33.1%, respectively, compared to those in the trees from industrial sites and by 19.7 and 25.2%, respectively, compared to those for roadside trees.

The range of the pigment content in the photosynthetic apparatus of conifers over the year depends on the climatic conditions and environmental factors of the urban technogenic environment as well as on the geographical position. The reduction of pigment rates was observed in the Metallurgical District, located in the southern part of the city where, to make it worse, the metallurgical plant—the "record holder" among air pollution sources—is situated.

Our research on the effects of atmospheric pollution by car exhaust gases and toxic industrial emissions on the chlorophyll pigment complex of coniferous plants in the Kryvyi Rih plantations has shown that the increase in the concentration of air pollutant significantly changes the number and proportions of individual components of pigment complex. The rapid plant response to stress, which occurs at the physiological and biochemical levels, further affects the vital state and plant ornamental features.

Discussion

The amount of chlorophylls *a* and *b* is of particular importance among the informative diagnostic indicators of the state of photosynthetic apparatus and the adaptive capacity of plants (Verma, Chandra, 2014). The largest amount of chlorophyll *a* in the needles of *P. abies* and *P. pungens* was observed in May by other researchers (Lepedus et al., 2003; Titova, 2013; Bessonova, Ponomar'ova, 2017). This is due to the sufficient rainfall in the start of vegetation, and optimal air temperature for the plant development, increasing during the next months. The minimum amount of chlorophyll *a* in the species from the genus *Picea*, as well as in another representative of the conifers, namely, *Pinus nigra* subsp. *pallasiana* (Lamb.), was registered during the second half of the summer and autumn (Deligöz et al., 2018). It is noted that during prolonged droughts, the destruction of chlorophyll *a* is greater than *b* (Pavlov, 2005).

Investigations on the pigment complex of coniferous plants in Izhevsk have proved that *Picea pungens* is characterized as a species more resistant to air pollution than *P. abies*, as the reaction of the first species pigment complex to adverse environmental conditions is detected only in conditions of high air pollution (Bukharina et al., 2016). The highest content of chlorophyll *a* (0.9–1.2 mg/g of wet weight) was observed in introduced plantations of *P. pungens* in control territories, and the lowest (0.6–0.9 mg/g of wet weight) was observed in those in roadsides (Bessonova, Ponomar'ova, 2017). Close to our results, the values of chlorophyll content *b* in the needles of *P. abies* (0.37 mg/g of wet weight) and *P. pungens* (0.51 mg/g of wet weight) were measured by Titova (2010, 2013) in trees from the Arboretum of the Ussuriisk region of Russia. In this regard, the results of our investigations agree with those published by other researchers.

It is known from earlier publications that pollutants weaken the accumulation of chlorophyll *b* more than chlorophyll *a*, which may reduce the activity of the photosynthetic apparatus and disrupt the metabolism of plants (Tuzhilkina et al., 1988; Lepedus et al., 2003). However, other researchers (Sergejchik, 2015; Bukharina et al., 2016), on the contrary, emphasize the predominance of quantitative changes in the content of chlorophyll *a* in the pigment complex of conifers in urban areas; the content of chlorophyll *b* remains relatively stable. In our case, the second variant of the dynamic changes of the pigment complex is confirmed: the increase in the level of pollution of the urban environment more significantly decreases the amount of chlorophyll *a* than *b*.

In a number of articles (Miron, Sumalan, 2015; Mikhailova et al., 2017; Afanas'eva, 2018; Bessonova, Grytsay, 2018), it has been shown that chlorophyll reacts sensitively to all changes in the metabolism and, in adverse conditions, changes in its total content ($a + b$) and the ratio of individual forms (a/b). As for such an indicator the amount of chlorophylls ($a + b$) we should note that the results of author's research in general are the same as others: in the needles of *P. abies* from Ussuriisk, it was 1.11–1.38 mg/g of wet weight (Titova, 2010), and in the needles of *P. pungens* from the city of Dnipro (Ukraine), it was 0.99–1.7 mg/g of wet weight (Bessonova, Ponomar'ova, 2017). The peculiarities of pigment accumulation in conifers during the vegetation period are also confirmed by other studies: the most intensively this process takes place in May (Titova, 2013; Bessonova, Ponomar'ova, 2017), the smallest number is observed in September (Zarek, 2016; Deligöz et al., 2018). Our data also proved the previously statements (Kvilala et al., 2014; Verma, Chandra, 2014; Starikova et al., 2016 Bessonova, Grytsay, 2018) on the overall decrease in the number of chlorophylls in plant photosynthetic apparatus under stress.

The data revealing the degree of stability of the photosynthetic apparatus of various coniferous plants to the effects of adverse factors still remain controversial. Some authors (Soukupova et al., 2001) stated that two species of spruce (*P. abies* and *P. pungens*) exhibit the same inhibition effects on functioning of the pigment complex under the influence of toxicants, whereas we have reasons to indicate a better adaptive balance of pigment content in *P. pungens*.

It was found that increased concentrations of air pollutants lead to a decrease in the ratio of chlorophylls and to an increase in the concentration of carotenoids (Bessonova, Ponomar'ova, 2017). In particular, an increase in the concentration of carotenoids in the needles of *P. pungens* in response to air pollution was detected in various macroclimatic conditions (Bukharina et al., 2016; Starikova et al., 2016; Bessonova, Ponomar'ova, 2017). Thus, the content of carotenoids in the needles of the introduced plantings of *P. abies* from the Arboretum of the Ussuriisk, where the air can be considered relatively "pure", amounted to 0.19–0.22 mg/g of wet weight (Titova, 2010). For the needles of the same tree species from the plantations of Osijek under conditions of atmospheric pollution with cement dust, this indicator was 0.21–0.25 mg/g of wet weight (Lepedus et al., 2003). Significantly larger quantities of this indicator (0.20–0.37 mg/g of wet weight) were observed in the needles of *P. pungens* from roadsides of the city of Dnipro (Bessonova, Ponomar'ova, 2017). Such data in general agree with our data, obtained during investigations in Kryvyi Rih Region. We believe that in our case, the increase in the concentration of carotenoids within pigment complexes of trees growing close to industrial enterprises and highways in comparison to those from low-contaminated areas show protective response to man-induced impacts.

Conclusion

The results of our study show that the industrial emissions and vehicle exhaust gases of air pollutants in Kryvyi Rih significantly affect the pigment complex in the needles of *P. abies* and *P. pungens*. The decrease in the content of chlorophylls *a* and *b* in the needles of both investigated species of the genus *Picea* was observed for 5 months in comparison with the control "clean" territory. In this case, the amount of chlorophyll *a* is reduced to a greater extent than chlorophyll *b*. It was found that the sum of the content of chlorophylls ($a + b$) and their ratio in the needles of *P. abies* and *P. pungens* during the growing season increased in the plantings remote from industrial enterprises and highways, reaching the maximum figures of the indicators in May and the minimum indices in September, which is due to a decrease in the intensity of the photosynthetic apparatus activity and an unfavorable decrease in the air temperature. The study has shown that with the increase in pollution rates, the content of carotenoids was increased, which is associated with their protective function, whereas the ratio of the sum of chlorophylls *a* and *b* to the number of carotenoids in the needles of both species, on the contrary, decreased. It was found that in *P. abies*, the content of all pigments has values smaller than *P. pungens*, which indicates higher stability assimilation apparatus of the latter. In connection with the above, we suggest possible implications of the pigment complexes of *P. abies* and *P. pungens* as year-round available bioindicators of the air pollution state.

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THE POSITION OF THE VISEGRÁD COUNTRIES BY CLUSTERING METHODS BASED ON INDICATOR ENVIRONMENTAL PERFORMANCE INDEX

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Abstract

Lukáč J., Mihalčová, B., Manová E., Kozel R., Vilamova Š., Čulková K.: The position of the Visegrád countries by clustering methods based on indicator Environmental Performance Index. Ekológia (Bratislava), Vol. 39, No. 1, p. 16–26, 2020.

With a growing number of negative environmental burdens, several countries have increasingly begun to address the issue of environmental protection through a number of measures. Such measures include higher spending on public health, conservation of natural resources, less emission to the air, efficiency of waste sorting, reduction of water pollution, and groundwater. The contribution is based on the Environmental Performance Index (EPI) values to perform a cluster analysis of selected countries - especially OECD (organisation for Economic Co-operation and Development) countries. The database needed for analysis is the EPI indicator for the years for 2008 to 2018. The result will be clusters that will include countries with similar results of the EPI indicators for the reference period. It will be important for us to track the position of the Slovak Republic in this analysis.

Key words: cluster analysis, environmental performance, EPI.

Introduction

The problem of preserving life on Earth is becoming a global problem. The present study is devoted to the issue of environmental pollution in the conditions of selected countries. Environmental performance is measured using the Environmental Performance Index (EPI). The EPI ranks 180 countries on 9 priority environmental issues in 2 objectives, including protection of human health and maintaining ecosystem vitality. The underlying objective of the EPI is to move the environmental debate from emotional and rhetorical arguments to more data- and evidence-based action that facilitates performance tracking and accountability of decision- makers (Hsu, Zomer, 2014). The Environmental Impact Assessment Directive (EIA Directive) has created a reference framework for the implementation of the system of environmental impact assessment (EIA) into the legal systems of the Member States of the European Union, including the countries belonging to the Visegrád Group (V4): Poland, Slovak Republic, the Czech Republic, and Hungary (Gałaś et al., 2015).

Theoretical background

Careful measurement of environmental trends and progress provides a foundation for effective policymaking. The 2018 EPI ranks 180 countries on 24 performance indicators across 10 issue categories covering environmental health and ecosystem vitality. These metrics provide a gauge at a national scale of how close countries are to established environmental policy goals. The EPI thus offers a scorecard that highlights leaders and laggards in environmental performance, gives insight on best practices, and provides guidance for countries that aspire to be leaders in sustainability (Yale University, 2019) (Fig. 1).

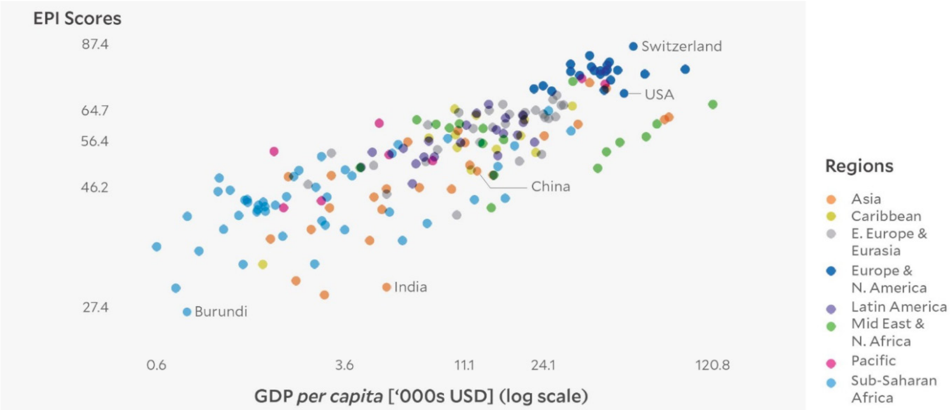
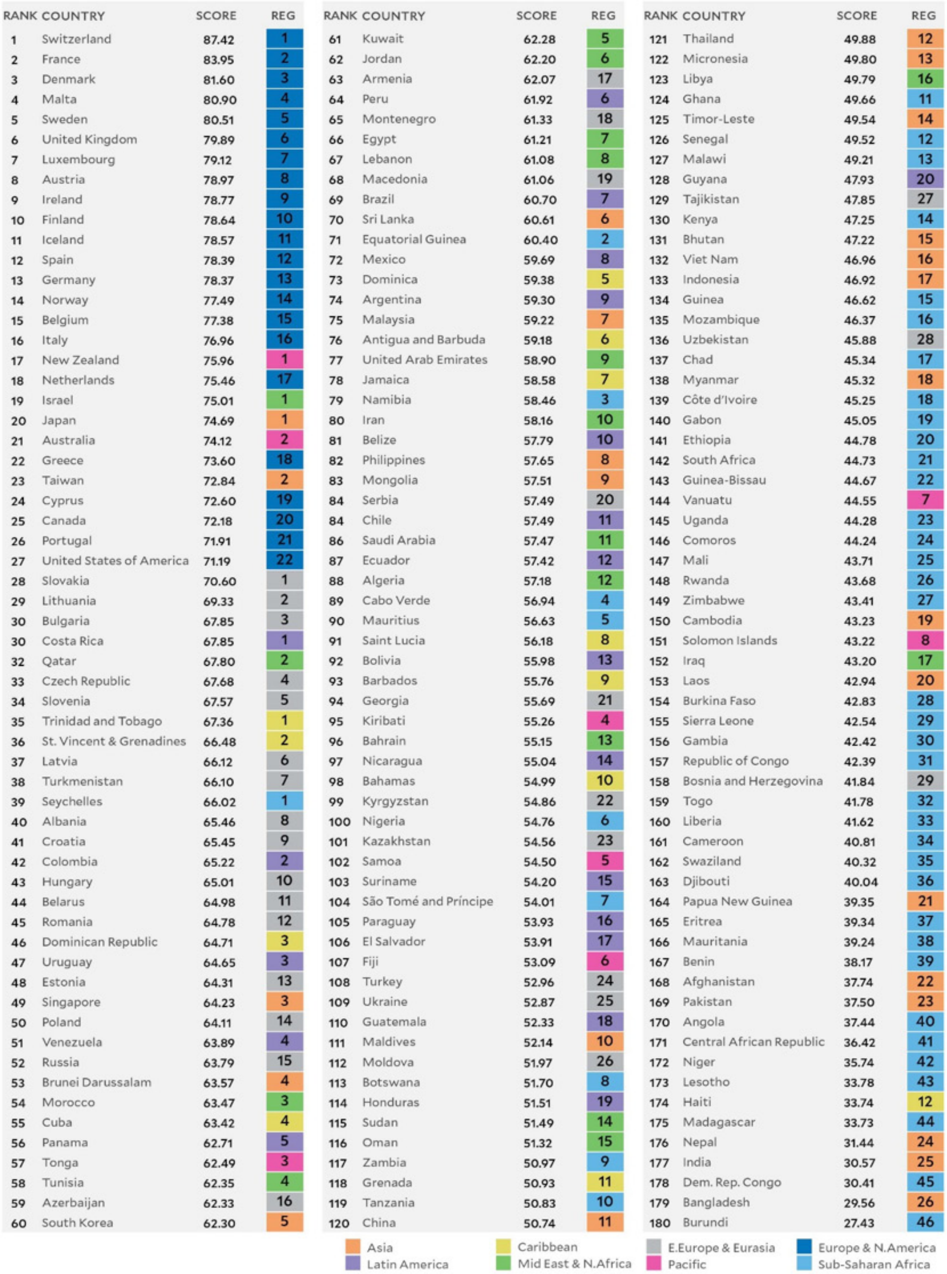


Fig. 1. Relationship between 2018 EPI Scores and GDP per capita.

France (83.95), Denmark (81.60), Malta (80.9), and Sweden (80.51) were the top 5 countries in the 2018 EPI. At the bottom of the 2018 EPI rankings are Nepal (31.44), India (30.57), the Democratic Republic of the Congo (30.41), Bangladesh (29.56), and Burundi (27.43). The Slovak Republic ranked 28th with an EPI index of 70.60. The results indicate that countries with lower EPI rating do not create money for environmental protection, air protection, water, andwaste separation. Countries with low EPI rating are often countries of the third world where the riots of civil unrest or war conflicts and most of the state budget expenditures are designed to ensure the basic course of the country. On the contrary, the country achieves a record high EPI in waste separation, expenses in public health, conservation of natural resources, and management of emissions and many other indicators (Table 1).

T a b l e 1. Results of EPI.



RANK	COUNTRY	SCORE	REG
1	Switzerland	87.42	1
2	France	83.95	2
3	Denmark	81.60	3
4	Malta	80.90	4
5	Sweden	80.51	5
6	United Kingdom	79.89	6
7	Luxembourg	79.12	7
8	Austria	78.97	8
9	Ireland	78.77	9
10	Finland	78.64	10
11	Iceland	78.57	11
12	Spain	78.39	12
13	Germany	78.37	13
14	Norway	77.49	14
15	Belgium	77.38	15
16	Italy	76.96	16
17	New Zealand	75.96	1
18	Netherlands	75.46	17
19	Israel	75.01	1
20	Japan	74.69	1
21	Australia	74.12	2
22	Greece	73.60	18
23	Taiwan	72.84	2
24	Cyprus	72.60	19
25	Canada	72.18	20
26	Portugal	71.91	21
27	United States of America	71.19	22
28	Slovakia	70.60	1
29	Lithuania	69.33	2
30	Bulgaria	67.85	3
30	Costa Rica	67.85	1
32	Qatar	67.80	2
33	Czech Republic	67.68	4
34	Slovenia	67.57	5
35	Trinidad and Tobago	67.36	1
36	St. Vincent & Grenadines	66.48	2
37	Latvia	66.12	6
38	Turkmenistan	66.10	7
39	Seychelles	66.02	1
40	Albania	65.46	8
41	Croatia	65.45	9
42	Colombia	65.22	2
43	Hungary	65.01	10
44	Belarus	64.98	11
45	Romania	64.78	12
46	Dominican Republic	64.71	3
47	Uruguay	64.65	3
48	Estonia	64.31	13
49	Singapore	64.23	3
50	Poland	64.11	14
51	Venezuela	63.89	4
52	Russia	63.79	15
53	Brunei Darussalam	63.57	4
54	Morocco	63.47	3
55	Cuba	63.42	4
56	Panama	62.71	5
57	Tonga	62.49	3
58	Tunisia	62.35	4
59	Azerbaijan	62.33	16
60	South Korea	62.30	5
61	Kuwait	62.28	5
62	Jordan	62.20	6
63	Armenia	62.07	17
64	Peru	61.92	6
65	Montenegro	61.33	18
66	Egypt	61.21	7
67	Lebanon	61.08	8
68	Macedonia	61.06	19
69	Brazil	60.70	7
70	Sri Lanka	60.61	6
71	Equatorial Guinea	60.40	2
72	Mexico	59.69	8
73	Dominica	59.38	5
74	Argentina	59.30	9
75	Malaysia	59.22	7
76	Antigua and Barbuda	59.18	6
77	United Arab Emirates	58.90	9
78	Jamaica	58.58	7
79	Namibia	58.46	3
80	Iran	58.16	10
81	Belize	57.79	10
82	Philippines	57.65	8
83	Mongolia	57.51	9
84	Serbia	57.49	20
84	Chile	57.49	11
86	Saudi Arabia	57.47	11
87	Ecuador	57.42	12
88	Algeria	57.18	12
89	Cabo Verde	56.94	4
90	Mauritius	56.63	5
91	Saint Lucia	56.18	8
92	Bolivia	55.98	13
93	Barbados	55.76	9
94	Georgia	55.69	21
95	Kiribati	55.26	4
96	Bahrain	55.15	13
97	Nicaragua	55.04	14
98	Bahamas	54.99	10
99	Kyrgyzstan	54.86	22
100	Nigeria	54.76	6
101	Kazakhstan	54.56	23
102	Samoa	54.50	5
103	Suriname	54.20	15
104	São Tomé and Príncipe	54.01	7
105	Paraguay	53.93	16
106	El Salvador	53.91	17
107	Fiji	53.09	6
108	Turkey	52.96	24
109	Ukraine	52.87	25
110	Guatemala	52.33	18
111	Maldives	52.14	10
112	Moldova	51.97	26
113	Botswana	51.70	8
114	Honduras	51.51	19
115	Sudan	51.49	14
116	Oman	51.32	15
117	Zambia	50.97	9
118	Grenada	50.93	11
119	Tanzania	50.83	10
120	China	50.74	11
121	Thailand	49.88	12
122	Micronesia	49.80	13
123	Libya	49.79	16
124	Ghana	49.66	11
125	Timor-Leste	49.54	14
126	Senegal	49.52	12
127	Malawi	49.21	13
128	Guyana	47.93	20
129	Tajikistan	47.85	27
130	Kenya	47.25	14
131	Bhutan	47.22	15
132	Viet Nam	46.96	16
133	Indonesia	46.92	17
134	Guinea	46.62	15
135	Mozambique	46.37	16
136	Uzbekistan	45.88	28
137	Chad	45.34	17
138	Myanmar	45.32	18
139	Côte d'Ivoire	45.25	18
140	Gabon	45.05	19
141	Ethiopia	44.78	20
142	South Africa	44.73	21
143	Guinea-Bissau	44.67	22
144	Vanuatu	44.55	7
145	Uganda	44.28	23
146	Comoros	44.24	24
147	Mali	43.71	25
148	Rwanda	43.68	26
149	Zimbabwe	43.41	27
150	Cambodia	43.23	19
151	Solomon Islands	43.22	8
152	Iraq	43.20	17
153	Laos	42.94	20
154	Burkina Faso	42.83	28
155	Sierra Leone	42.54	29
156	Gambia	42.42	30
157	Republic of Congo	42.39	31
158	Bosnia and Herzegovina	41.84	29
159	Togo	41.78	32
160	Liberia	41.62	33
161	Cameroon	40.81	34
162	Swaziland	40.32	35
163	Djibouti	40.04	36
164	Papua New Guinea	39.35	21
165	Eritrea	39.34	37
166	Mauritania	39.24	38
167	Benin	38.17	39
168	Afghanistan	37.74	22
169	Pakistan	37.50	23
170	Angola	37.44	40
171	Central African Republic	36.42	41
172	Niger	35.74	42
173	Lesotho	33.78	43
174	Haiti	33.74	12
175	Madagascar	33.73	44
176	Nepal	31.44	24
177	India	30.57	25
178	Dem. Rep. Congo	30.41	45
179	Bangladesh	29.56	26
180	Burundi	27.43	46

🟧 Asia
🟪 Latin America
🟨 Caribbean
🟩 Mid East & N.Africa
⬜ E.Europe & Eurasia
🟥 Pacific
🟦 Europe & N.America
🟦 Sub-Saharan Africa

In addition to the EPI, other measurement tools are also used for measuring environmental performance. Complimen integrates parts of tools such as life cycle assessment, multi-criteria analysis, and environmental performance indicators. The popular "balanced scorecard" system can be applied in the selection and development of environmental performance indicators. As presented, the balanced scorecard integrates environmental performance within the context of corporate strategic objectives. (Johnson, 1998) EMS (Environmental management system) is a tool for managing the interaction between the organization and the environment. The aim of an EMS is to improve the overall environmental performance of the organization. The performance should be monitored through measurements, and managed by indicators. Indicators are variables that summarize or otherwise simplify relevant information about the state of a complex system. A correct evaluation of environmental performance arises from the choice of adequate "raw" data and from the relationships among "raw" data (Perotto et al., 2008).

Zhou et al. (2015) developed two slack-based efficiency measures for modeling environmental performance based on environmental DEA (Data envelopment analysis) technology. They applied the proposed measures to model the CO_2 emissions in 30 OECD countries from 1998 to 2002 and presented the results obtained. Stanwick (1998) examined the relationship between the corporate social performance of an organization and three variables: the size of the organization, the financial performance of the organization, and the environmental performance of the organization. The cost-concerned school argues that environmental investments represent only increased costs, resulting in decreased earnings and lower market values. The value creation school regards environmental efforts as a way to increase competitive advantage and improve financial returns to the investors. The current research finds support for the cost-concerned school, because the results indicate that environmental performance has a negative influence on the market value of firms (Hassel et al., 2005).

According to Nakao et al. (2007), when we consider only scores of those companies that published the relevant information in their environmental reports, and conduct the statistical causality test with such information as additional input to the pooled time-series and cross-section data of financial performance, the results become more strongly significant. From the experience of environmental policies in Japan, we infer that information-based environmental policy measures are effective to encourage the ongoing transition toward a more sustainable market economy. In order to evaluate current sustainability performances of European countries from the environmental and energetic perspectives, this research proposes a multi-criteria decision analysis that, starting from both Eurostat data and the Analytic Hierarchy Process, allows a direct comparison of nations. The results show that, even nowadays, 12 of 28 European countries have a value greater than the average of values for European countries in 2013. Top four nations (Sweden, Denmark, Finland and Austria) have high indexes of sustainability and Sweden is the best country from both the environmental and energetic perspectives (Cucchiella et al., 2017).

According to Zuo (2017) the results of his research indicate that the EPI of 30 provincial administrative regions (PARs) from 2006 to 2011 ranges from 44.12 (Shanxi, 2006) to 80.87 (Beijing, 2010), from poor to good, respectively. To help develop more effective policies to improve China's regional environmental performance, cluster analysis is applied to divide the 30 PARs into 3 sub-regions. Recommendations for improving the environmental performance of different sub-regions are made to help guide the Chinese government to adjust environmental governance approaches to local conditions. In the article by Song et al. (2018), he first reviewed the literature on environmental performance evaluation, including evaluation theories, the methods of data envelopment analysis, and the technologies and applications of life cycle assessment and the ecological footprint. Then, he presented the theories and technologies regarding big data and the opportunities and applications for these in related areas, followed by a discussion on problems and challenges. According to the research of Haque and Ntim (2018), his evidence suggests that firms can symbolically conform to environmental policy Coca-Cola Amatil and sustainable development frameworks (GRI 307: Environmental Compliance, policy of the University of North Carolina at Greensboro) by engaging in color rendering index without necessarily improving actual environmental performance (greenhouse gas emissions) substantively.

Urbaniec (2014) identifyied the importance and relevant practices related to international standards for environmental management system in the countries of the Visegrád Group (Slovak Republic, the Czech Republic, Poland and Hungary). Papiez (2013) examined causal relationships among carbon dioxide emissions, energy consumption and economic growth using panel vector error correction modeling techniques based on the panel data for the Visegrad Group countries for the period 1992–2010. Panel co-integration tests show the existence of long-run relationships among carbon dioxide emissions, energy consumption and economic growth. The long-run equilibrium indicates that energy consumption has a positive and statistically significant impact on emissions. However, the results obtained cannot confirm the Environmental Kuznets Curve hypothesis for the Visegrád Group countries.

The environmental burden of the country in the context of tourism was analyzed by Drábova-Degro, and Krnáčová (2017). While evaluating the selected town-planning, demographical, and social economic indicators, we quantified the selective landscape preconditions of tourism development. The realization preconditions were reviewed according to communication accessibility and material technical equipment. As for environmental preconditions, we reviewed the presence of protected territory and landscape environmental load. Another analysis by Kapusta et al. (2018) dealt with the impact of environmental changes on the lakes in the Tatra Mountains. Overgrowing of shallow moraine lakes lying in the vegetation zone is a significant phenomenon of the High Tatras alpine landscape. It leads to their gradual extinction, turning into peat bogs and wet alpine meadows.

From the values emanate from the element analysis of roe deer teeth from three polluted sites (Žiar, Spiš, and Orava sites) and the control locality in the Nízke Tatry National Park, Maňkovská et al. (2012) found the highest concentrations of As, Cd, Co, Cu, Hg, Na, Pb, Rb, Sr, and Zn in the roe deer teeth and observed a statistically significant difference in the concentration of As, Cd, Co, Cu, Hg, Na, Pb, Rb, Sr, and Zn in roe deer teeth obtained from the three sites and the control locality of NAPANT. This obtained data are a useful reference point for the comparison with future measurements of air pollution in the examined area, whenever hazards due to heavy metal accumulation in the food chain are assessed.

The relationship between mining activity and landscape ecology was analyzed by Rahmonov and Szymczyk (2010). Open-mined sand exploitation always leads to the total liquidation of vegetation and soil cover. The given study presents the relations between vegetation appearing in the excavation and soil development in the initial phases of succession. Investigations were carried out in the Kuznica Warezynska sandpit located in the Silesian Upland in southern Poland. The results obtained indicate that at uncovered sands, because of exploitation in unreclaimed places, spontaneous regeneration of vegetation soil cover occurs.

Methodology

The main aim of this contribution is to identify the location of the Slovak Republic and other countries of the Vysegrád group using the clustering method. The data on which we are based represent the database of values of EPI indicators achieved for 2008, 2010, 2012, 2014, 2016 and 2018. The data obtained from this portal are first analyzed by cluster analysis using the mathematical and statistical software R-studio.

We applied the cluster analysis procedure according to Stankovičová, and Vojtková (2007). The procedure for the application of cluster analysis is given as follows:

- entering input data,
- selecting the type of variables,
- object names,
- selection of the agglomeration process,
- selection of the type of aggregation method,
- selection of the degree of similarity of objects,
- determining the number of significant clusters,
- interpretation of clusters.

For the selection of the degree of similarity of objects, we applied a distance measure called Euclidean distance, that is formulated as follows:

$$d_{ij} = \sqrt{\sum_{k=1}^{n} \left(X_{ik} - X_{jk}\right)^2} \ ,$$

where

X_{ik} is the value of the *kth* variable for the *ith* enterprise,

X_{jk} is the value of the *kth* variable for the *jth* enterprise.

This distance assumes an orthogonal coordinate system, which means mutual non-correlation of variables. The disadvantages of this type of distance include the significant influence of the absolute value (amount) of input data. This disadvantage can be eliminated by using variables in their standardized shape (form) (Stankovičová, Vojtková, 2007).

In terms of the type of aggregation (clustering) method, we have applied Ward‘s method (Ward‘s minimum variance method), which is the most used in practice. According to this method the clusters are formulated based on the maximization of homogeneity within the cluster. The homogeneity measure represents the sum of squares of deviations from the average of the cluster, called the error sum of squares (ESS) and we use the following formula for its calculation:

$$ESS = \sum_{i=1}^{n_h} \sum_{h=1}^{q} \left(X_{hi} - \overline{X}_{C_h}\right)^2 \ ,$$

where

n_h is the number of objects in the cluster C_h,

$\overline{X}_{C_h}$ is the vector of the average of the values of the character in the cluster C_h,

X_{hi} is the vector of the values of the character of *ith* object in the cluster C_h.

The cluster analysis is designed to create relatively homogeneous groups where it is necessary to determine an appropriate number of these groups based on various criteria, for example based on the hierarchical tree dendrogram (Stankovičová, Vojtková, 2007).

By performing the correlation of the input variables at a significance level of 5% (α = 0.05), we observed the dependence (relationship) among the variables. However, the problem may be a high degree of dependence (relationship) among variables, which can affect the classification results. Deletion of the problem can be accomplished through the main components´ method, in which input indicators are transformed into the new variables called as main components and they are already independent of each other. Only a few main components can reliably explain a substantial part of the overall spread of the original data. Therefore, several rules are used to determine the optimal number of components, for example,

- the number of main components should explain at least 70% of the total spread of the data,
- the number of main components determined to be used in a graphical representation of the spread is explained by main components.

Research

A prerequisite for performing cluster analysis is to examine the relationships among individual variables. The starting point for us was a correlation matrix that contains Pearson‘s correlation coefficients (Fig. 2).

Previously figure shows that for example in the case of the variables x2018, x2016 and x2012, all coefficients are statistically insignificant. But in case of the variable x2014, some of their correlations are statistically significant. This means that there may be a problem with cluster formation in cluster analysis. Therefore, it is necessary to use the main component method (to analyze the main components). We used the type of main components analysis that works with standardized variables. For the purpose of identifying the optimal number of main components (number of significant components), we calculated the shares of components variability in the total variability of the data from which we calculated the components (Table 2).

We can see that the first component explains the most variability and the last component explains the least variability. At the same time, we see that in order to clarify 79.189% of the variability of the original data, we need only 2 components. So we can say that we have met a rule that says the number of main components should explain at least 70% of the total spread of data. Subsequently, we also explained the variability of the original data by the components graphically using scree plot, where a graphical representation of the spread is explained by main components

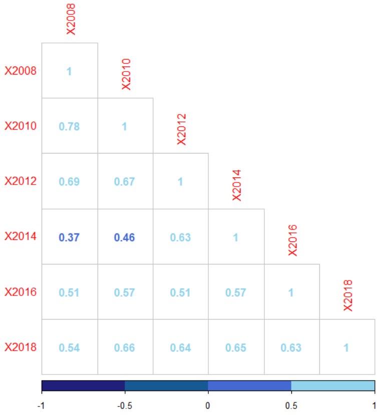


Fig. 2. Pearson correlation matrix.

Table 2. Main component.

	PC1	PC2	PC3	PC4	PC5	PC6
Standard deviation	1.994021	0.8804743	0.7068837	0.5785763	0.4822549	0.4261946
Proportion of variance	0.662690	0.1292100	0.0832800	0.0557900	0.0387600	0.0302700
Cumulative proportion	0.662690	0.7918900	0.8751700	0.9309600	0.9697300	1.000000

and we found a break in the graph (Fig. 3).

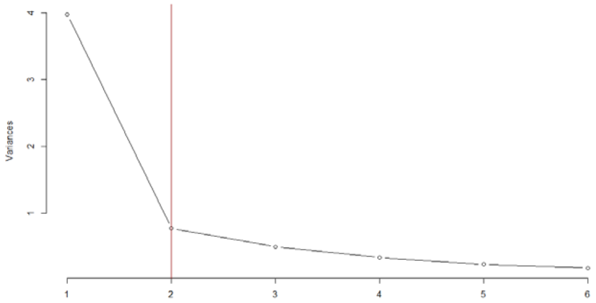


Fig. 3. Screeplot of main component.

On the basis of our selection, 4 main components were selected for cluster analysis, and a hierarchical tree diagram, also called as a dendrogram, was obtained (Fig. 4).

The next step was the determination of the number of significant clusters of enterprises in our analysis. On the basis of the heuristic approach, we grouped the enterprises into 4 clusters. For this determination we also used the scree plot of number of clusters, where the number of clusters is on the x-axis and the within cluster sum of squares is shown on the y-axis. The decisive criterion is to minimize the within cluster sum of squares, which represents the optimal situation (Fig. 5).

If we decide for more clusters, the within sum of squares would cause that the number of countries in the cluster would be too small, and conversely, a small number of clusters would cause that the within sum of squares would be too high. The number of countries in each cluster is presented (Table 3).

Subsequently, we have plotted the clusters in the hierarchical tree diagram, where the individual clusters are marked. Each enterprise is marked with a number (the name of country). We can see that four clusters have been created, which are mutually heterogeneous but en-

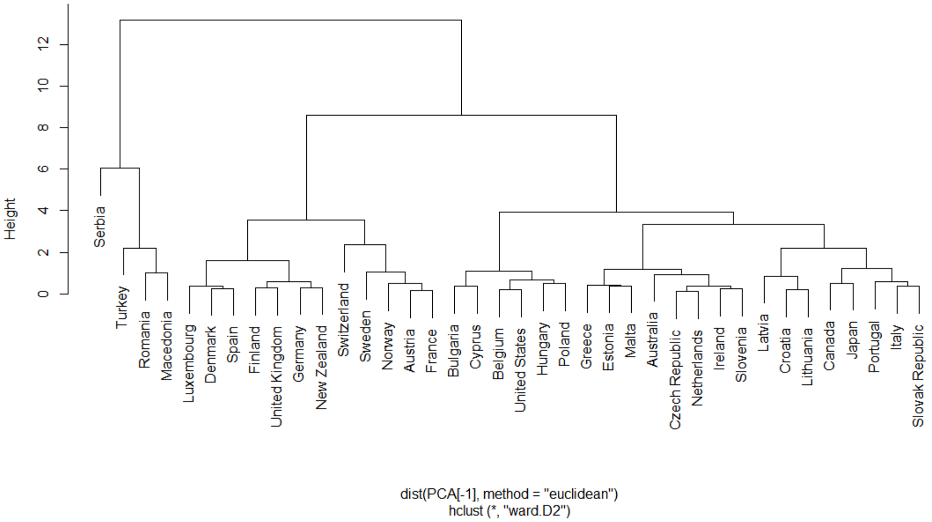


Fig. 4. Dendrogram.

terprises within their cluster are homogeneous. This means that countries in one cluster have similar characteristics in terms of EPI with countries in other agglomerations (clusters) (Fig. 6).

From the results of the dendrogram itself, it is clear that the group of analyzed countries was divided into four separate clusters. The first cluster includes 12 countries, the second cluster of 22 countries, the third cluster 3 countries, and the last cluster 1 country. On the basis of the above, we can say that the Slovak Republic has ranked among the most numerous clusters together with our neighbors in the Czech Republic, Poland, Hungary, and Austria. We can also say that the countries that are in the cluster with the Slovak Republic are those that reach above average values of the EPI indicator. A cluster of 12 countries is represented by countries such as Sweden, Norway, New Zealand, and other countries that are long-term mentors in the field of reducing negative environmental impacts. Slovak Republic is in the second cluster.

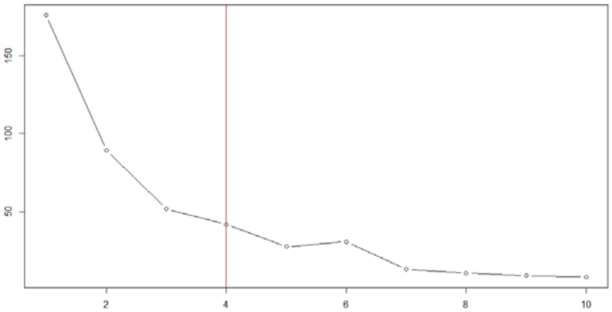


Fig. 5. Screeplot of significant cluster.

Table 3. Screeplot of significant cluster.

Cluster	Number of country
1.	12
2.	22
3.	3
4.	1

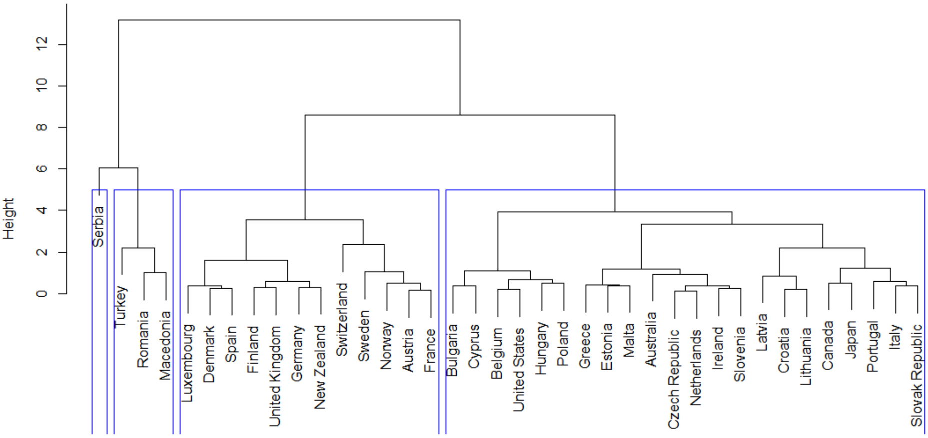


Fig. 6. Dendrogram with four clusters.

Conclusion

Table 4. Centroids of cluster.

Cluster no.	**2008**	**2010**	**2012**	**2014**	**2016**	**2018**
1	88.50	76.30	67.72	78.60	87.84	80.02
2	82.43	67.20	60.97	71.38	84.96	71.26
3	74.30	62.67	46.70	51.93	76.30	59.60
4	36.50	42.50	46.10	69.10	78.70	57.49

Table 5. Medians of cluster.

Cluster no.	**2008**	**2010**	**2012**	**2014**	**2016**	**2018**
1	88.35	74.45	68.80	78.05	87.70	79.05
2	83.45	66.75	61.15	72.75	85.25	71.55
3	75.10	60.59	47.00	50.50	78.00	61.06
4	36.50	42.50	46.10	69.10	78.70	57.49

The result of our analysis is the location of clustered countries based on the EPI indicator values between 2008 and 2018. On the basis of the analysis, using the Ward Method and the Euclidean Distance, we created 4 clusters containing selected OECD countries. As a result, the Republic of Slovakia joined the group no. 2, which includes the other countries of the Visehrád group - Poland, Hungary, the Czech Republic, and Austria. The average for centorids for each year by the EPI indicator is presented in Table 4.

From the table, we can say that the average value of the EPI indicator varies from 2008 to 2018. For the second cluster, where the Slovak Republic is located, the average value of the indicator is 82.23 in 2008 and gradually decreases in 2010 and 2012 to 67.20 and 60.97, respectively. An increase in the indicator in 2014 and 2016 signals an improvement, but again in 2018, it drops to levels 71, and 26. We can see that even in comparison with the values for years with other clusters, cluster no. 2 is in second place (Table 5).

The previous table informs about the average values of the EPI pointer. The gap between centroid and median for clustering is that the median removes the extreme values of the EPI pointer, which may be in the clusters of the individual countries, thereby reducing the distortion of the analysis and rendering the ability of the EPI pointer. At cluster no. 2, which is also the Slovak Republic, this distortion is around ± 1 point.

Similar results were also obtained form in the area studied, which were in the V4 countries. Vološčuk et al. (2016) presented the results acquired by an ecological analysis of vegetation succession on the field of the Slovak Karst in south-east Slovakia for the past 25 years. Fazekáš et al. (2018) focused on the impacts of alkaline and metal deposition on soil and vegetation in the immission field of a magnesium factory in Jelšava-Lubeník (Slovakia).

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CHANGES IN PHYSICAL AND CHEMICAL PROPERTIES OF CALCIC CHERNOZEM AFFECTED BY *Robinia pseudoacacia* AND *Quercus robur* PLANTINGS

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Abstract

Gorban V., Huslystyi A., Kotovych O., Yakovenko V.: Changes in physical and chemical properties of Calcic chernozem affected by *Robinia pseudoacacia* and *Quercus robur* plantings. Ekológia (Bratislava), Vol. 39, No. 1, p. 27–44, 2020.

Growth of forest plantations on soils causes changes in their properties. These changes, their behavior, and magnitude depend on the original soil characteristics and also on the effect of forest plantations being grown. In the steppe zone of Ukraine, *Robinia pseudoacacia* L. and *Quercus robur* L. are the woody species most widely used in planting of forest plantations on chernozem soil. Chernozem soil formed exclusively under zonal steppe vegetation and chernozem soil under *Robinia pseudoacacia* and *Quercus robur* plantations were studied in this work to analyze the changes in soil properties caused by growth of these tree species. Dry aggregate size distribution, density, particle density, total porosity, organic carbon content, cation exchange capacity, pH values, hydrolytic soil acidity and dry residue, and the available nitrogen, phosphorus, and potassium content were analyzed. The studies found that *Robinia pseudoacacia* and *Quercus robur* plantations contribute to an increase in the share of aggregates 2–1 mm in size, as well as formation of aggregate fraction >10 mm, which are completely absent in the Calcic chernozem developed under the steppe vegetation. An increase in the density and particle density, as well as a decrease in the total porosity values were observed under the influence of forest stands studied. This is more common with chernozem under *Q. robur* plantation. It was found that the carbon percentage decreased in chernozem under the influence of *Robinia pseudoacacia* growth (on average, 0.4% by a meter-deep layer), but under *Quercus robur* planting it increased (on average 0.3% by meter-deep layer). Effect of *Robinia pseudoacacia* plantings on chernozem was also manifested by a decrease in cation exchange capacity (on average, 11 cmol/100 g by a meter-deep layer). The growth of *R. pseudoacacia* and *Quercus robur* plantations results in decrease of pH values (0.2 by a meter-deep layer) and increase of hydrolytic soil acidity and dry residue in chernozem water extract. Effect of *Robinia pseudoacacia* planting leads to a decrease in carbon, nitrogen, and phosphorus content in chernozem. The change in chernozem properties under the influence of *Quercus robur* plantation is reflected in accumulation of these nutrients. Growth of *Robinia pseudoacacia* and *Quercus robur* plantations leads to a decrease in potassium reserves in chernozem, which may indicate its active uptake by these woody species. In general, *Q. robur* planting is characterized by a large positive effect on the physical and chemical properties of chernozem than *Robinia pseudoacacia* planting. The findings obtained serve as a ground for making a recommendation for growing *Quercus robur* plantations under climate conditions of the steppe zone of Ukraine in order to improve the zonal chernozems' state and fertility.

Key words: chernozem, dry aggregate size distribution, total porosity, soil organic carbon, forest plantation, steppe zone.

Introduction

Land degradation is one of the most common and important problems in the modern age, on which human security will depend in the near future (Amundson et al., 2015; Webb et al., 2017). This problem is relevant for most countries worldwide (Chappell et al., 2019; Jiang et al., 2019; Wunder, Bodle, 2019). Land degradation is closely related to the possible consequences of climate changes observed nowadays (Bonfante et al., 2019; Netsvetov et al., 2018; Zhou et al., 2019).

In Ukraine, the most common processes of soil degradation are the following: losses of humus and nutrients, overconsolidation, acidification, waterlogging, water and wind erosion, contamination with radionuclides, pesticides, and other organic substances, heavy metals, and soil aridization (Medvedev et al., 2014).

Artificial afforestation is one of the most effective measures for ecological soil restoration, protection for them water and wind erosion, and soil fertility restoration to reduce soil and land degradation (An et al., 2010; Gu et al., 2019; Lal, 2004; Ritter et al., 2003). As a whole, native and artificial forests perform an effective protective function against degradation of soil cover, especially in limiting the loss of humus and in topsoil protection (Wiśniewski, Märker, 2019). Both local and introduced arboreal species can be used for afforestation (Li et al., 2012). To maximize the benefits of afforestation efforts, it is necessary to take into account the particularities of the tree species used as well as of the plantation age (Sun et al., 2018; Zhang et al., 2018). Tree species can influence biological, chemical, and physical properties of soils directly through their deep roots, as well as through litter quality and quantity (Day et al., 2010; Edmondson et al., 2014). Changes in soil properties after afforestation are different and they depend on previous land use and vegetation types (Guo, Gifford, 2002; Jobbagy, Jackson, 2000).

The study of pattern of changes in soil organic carbon content in Calcic chernozem caused by cultivation of woody plantations is very important in understanding the characteristics of absorption and release of greenhouse gases in conditions of the steppe zone of Ukraine. The intensity of soil organic carbon sequestration and its conservation in the soil depends on the complex interactions between climate, soil, woody species, and management, as well as on the chemical composition of leaf litter determined by the dominant woody species (Lal, 2005). Based on similar studies conducted in other countries, majority of the researchers concluded that forest planting in arable land leads to increase in carbon sequestration and nitrogen accumulation in soils (Foote, Grogan, 2010; Sauer et al., 2012; Ussiri et al., 2006). The maximum intensity of increasing carbon and nitrogen reserves was observed in upper soil horizons, to a depth of 55 cm (Clark, Johnson, 2011). It was noted that soil organic carbon sequestration increases with the planting age (Berthrong et al., 2012; Boussougou et al., 2010; Jiao et al., 2011). Coincidently, it has been observed that soil carbon loss may occur in the first decades after planting of tree species and is followed by a recovery stage of unknown duration (Bárcena et al., 2014). It was found that the carbon sequestration value is largely determined by the species composition within tree plantations (Gurmesa et al., 2013). At the same time, plantations from broad-leaved trees placed on the lands of previous native forests or pastures did not significantly affect soil carbon stocks, while pine plantations reduced soil carbon stocks by 12–15% (Guo, Gifford, 2002; Paul et al., 2002).

A comprehensive study of vegetation and wildlife of steppe forests has shown the importance to enlarge the woodland territories for the benefit of biological diversity conservation

(Baranovski et al., 2018; Brygadyrenko, 2014, 2015, 2016). However, today, the influence of forest vegetation on the stability of soil aggregates and soil physical and chemical properties remains insufficiently studied in the steppe regions (Zhang et al., 2018). On this basis, the purpose of our work was to study the pattern of changes in aggregate size distribution and some physical and chemical properties of Calcic chernozem under the influence of black locust (*Robinia pseudoacacia* L.) and common oak (*Quercus robur* L.) plantations in the national park "Samarskiy Bir", Ukraine.

Material and methods

Site characteristics

Field surveys were carried out on the territory of the national park "Samarskiy Bir" (Fig. 1) located within the southeastern part of the steppe zone of Ukraine (Novomoskovskiy rayon, Dnipropetrovsk oblast, Ukraine).

Site 1 was located within the virgin steppe land of watershed plateau (southeastern part of the Andreevka village, 48°45'36.9"N, 35°27'40.5"E). Herbaceous vegetative cover was closed, consisting of *Festuca valesiaca* Schleich. ex Gaudin, *Koeleria macrantha* (Ledeb.) Schult., *Thymus marschallianus* Willd., *Linum hirsutum* L., *Salvia nemorosa* L., *Artemisia austriaca* Jacq., and other herbaceous plant species. Groundwater depth was about 40 m.

Site 2 was laid on the watershed plateau (westward of Vsesviatske village, 48°45'27.6"N, 35°29'33.4"E). Groundwater depth was 40 m below the ground surface. Forest stands were represented by *Robinia pseudoacacia* L. aged about 60 years. The average tree height was 4–6 m and the stem diameter was 10–12 cm. Stand canopy density was 0.7. Type of tree planting was line. The drilling distance was 0.5 m and the distance between rows was 1 m. *Elytrigia repens* L., *Poa angustifolia* L., and *Chelidonium majus* L. predominate in the herbaceous cover, with a total coverage of about 60–70%.

Site 3 (48°45'27.0"N, 35°30'09.5"E) was located on a watershed plateau next to Site 2. Forest stand was represented by *Quercus robur* L., aged about 60 years. The average tree height was 7–9 m and the stem diameter was 10–14 cm. Stand canopy density was 0.9. Type of tree planting was line. Rows of oak trees were alternated with rows of shrubs: *Acer tataricum* L. and rarely *Euonymus europaeus* L. The distance between rows was 0.75 m and the drilling

Fig. 1. Location of the sites in the territory of the National Park "Samarskiy Bir" (Novomoskovskiy rayon, Dnipropetrovsk oblast, Ukraine).

distance was 1.5 m. In the herbaceous cover, *Elytrigia repens* L., *Verbascum lychnitis* L., *Salvia verticillata* L., and *Ajuga genevensis* L. predominate, with a total coating of about 20–25%.

Sample procedures

About 1 kg of the composite soil sample was selected on each of the three sites in the summer of 2017. Samples were taken from the middle of each 20-cm layer, to a depth of 100 cm. The soil samples selected were later used for laboratory determination of their structural and aggregative state and physical and chemical properties.

Laboratory analyses

Field description of soil profiles was carried out according to the guidelines for soil description (2006). Classification position of the studied soils was determined in accordance with the IUSS Working Group WRB 2015.

Air-dried soil samples were used in laboratory studies. Dry aggregate size distribution and physical and chemical soils properties were determined in accordance with the Soil Sampling and Methods of Analysis (Carter, Gregorich, 2008) recommendations. Aggregate size distribution of soils was determined by sifting of dry samples using a standard sieve set (mesh sizes 10, 7, 5, 3, 2, 1, 0.5, and 0.25 mm). The results of sieve analysis were expressed in terms of the percentage of the total weight of soil that passed through different sieves to the weight of total soil sample used for this analysis. Bulk density (D_b) was defined as the weight of soil particles divided by the total soil volume. For this purpose, field soil samples of about 1000 cm^3 each were taken with a hand probe, followed by weighing in the laboratory with parallel determination of field humidity. Particle density (D_p) was determined using a glass pycnometer with a volume of 100 cm^3 and 10 g of soil sample. The total porosity S_t may be calculated using the particle density and bulk density values as $S_t = (1 - D_b/D_p) \times 100$. Determination of soil organic carbon was based on the chromic acid wet oxidation method, wherein the soil oxidizable matter is oxidized by a solution of potassium bicarbonate ($K_2Cr_2O_7$) at a temperature of 140–150 °C with subsequent titration of the remaining dichromate with ferrous sulfate (Mohr's salt) ($(NH_4)_2SO_4 \cdot FeSO_4 \cdot 6H_2O$). Available potassium and phosphorus were extracted with an acetic acid-based (0.5 mol/dm^3) chemical extractant at a soil-to-solution ratio of 1:25. Available potassium was determined by flame photometry method using flame photometer PFP-7/S; amount of available phosphorus was determined with molybdenum blue phosphorus method. Easily hydrolyzable nitrogen was determined with Kornfield method based on the hydrolysis of the soil organic compounds with an alkali solution (NaOH – 1 mol/dm^3) in Conway vessels. As a result of hydrolysis, nitrogen in the form of $NH_4 + NO_3$ obtained from diffusion was absorbed by a solution of boric acid and was determined by titration with a sulfuric acid solution. Determination of potential cation exchange capacity was carried out in accordance with the international standard ISO 13536: 1995, IDT in buffered barium chloride extracts using triethanolamine, pH = 8.1. Unreacted magnesium was determined using atomic absorption spectrophotometer C-115 at a wavelength of 285.2 nm. Determination of water pH was carried out in an aqueous extract prepared at a 1:5 soil to water ratio after 5-minute shaking. In the same extract, the total amount of water-soluble substances was determined with conductometric method using EZODO-7021.

Statistical analysis

Data obtained were analyzed with Statistica 6.0 (StatSoft Inc., 2012, Tulsa, OK, USA). Data were tabulated as x ± standard deviation (x ± SD). The differences between the control and experimental group values were determined using the Tukey test, where the differences between the samples were considered significant at $p < 0.05$ (taking into account the Bonferroni correction).

Results and discussion

Effect of tree plantations on the morphological structure of genetic horizons of Calcic chernozem

The soil studied was characterized by uniformity of morphological structure along the profile (Table 1).

T a b l e 1. Morphological description of the soils studied.

Horizon	Depth, cm	Color*	Structure**	Consistency	Field estimation of the textural classes	Carbonate content	The forms of secondary carbonates	Biological activity	
								Abundance of roots	Other biological features
Site 1 – Calcic chernozem (siltic, tonguic) under steppe vegetation									
0	3–0	Grass litter	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
A1	0–7	2.5 YR 4/1	Granular Subangular blocky	Slightly hard	Silt loam	Non-calcareous	–	Many	Worm and insect casts
A2	7–26	2.5 YR 4/4	Subangular blocky Granular Prismatic	Slightly hard	Silt loam	Non-calcareous	–	Many	Worm and insect casts Mole passages
Bk1	26–42	2.5 YR 5/3	Subangular blocky Prismatic Granular	Hard	Silt loam	Moderately calcareous (carbonate effervescence from 32 cm)	Not observed	Common	Worm and insect casts Earthworm channels Pedotubules
Bk2	42–57	2.5 YR 7/3	Subangular blocky Angular blocky Prismatic	Very hard	Silt loam	Strongly calcareous	Disperse powdery lime	Few	Earthworm channels Pedotubules Mole passages
Ck	57–130+	2.5 YR 7/2	Prismatic Subangular blocky Angular blocky	Very hard	Silt loam	Extremely calcareous	Soft concretions Disperse powdery lime	Very few	Earthworm channels Pedotubules Mole passages
Site 2 – Calcic chernozem (siltic, tonguic) under *Robinia pseudoacacia* plantation									
0	3–0	Leaf litter	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
A	0–14	2.5 YR 4/2	Granular Subangular blocky	Slightly hard	Silt loam	Non-calcareous	–	Many	Worm and insect casts
B	14–34	2.5 YR 6/3	Subangular blocky Prismatic Granular	Hard	Silt loam	Non-calcareous	–	Common	Worm and insect casts Earthworm channels Pedotubules

T a b l e 1. Morphological description of the soils studied. (continuation)

Horizon	Depth, cm	Color*	Structure**	Consistency	Field estimation of the textural classes	Carbonate content	The forms of secondary carbonates	Biological activity	
								Abundance of roots	Other biological features
Bk	34–56	2.5 YR 7/2	Prismatic Subangular blocky Angular blocky	Hard	Silt loam	Moderately calcareous (carbonate effervescence from 53 cm)	Not observed	Common	Worm and insect casts Earthworm channels Pedotubules
Ck	56–120+	2.5 YR 7/2	Subangular prismatic Subangular blocky Angular blocky	Very hard	Silt loam	Strongly calcareous	Soft concretions Disperse powdery lime	Very few	Earthworm channels Pedotubules
Site 3 – Calcic chernozem (siltic, tonguic) under *Quercus robur* plantation									
0	4–0	Leaf litter	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
A1	0–9	2.5 YR 2/1	Granular Subangular blocky	Slightly hard	Silt loam	Non-calcareous	–	Many	Worm and insect casts
A2	9–42	2.5 YR 2/1	Subangular blocky Granular	Slightly hard	Silt loam	Non-calcareous	–	Many	Worm and insect casts
Bk1	42–62	2.5 YR 4/2	Subangular blocky Granular	Hard	Silt loam	Moderately calcareous (carbonate effervescence from 48 cm)	Not observed	Common	Worm and insect casts Earthworm channels Pedotubules Mole passages
Bk2	62–81	2.5 YR 5/2	Subangular blocky Angular blocky Subangular prismatic	Very hard	Silt loam	Strongly calcareous	Disperse powdery lime	Common	Earthworm channels Pedotubules Mole passages
Ck	81–120+	2.5 YR 7/4	Angular blocky Subangular prismatic Subangular blocky	Very hard	Silt loam	Extremely calcareous	Soft concretions Disperse powdery lime	Very few	Earthworm channels Pedotubules Mole passages

Notes: * – color of the soil matrix in humidified state; ** – types of soil structure are indicated in order of decreasing relative content of peds with corresponding morphology; n.a. – not analyzed; – – missing.

Granulometric composition throughout the profile showed presence of silt loam. The consistency of the soil material varied from slightly hard in the surface horizons A to very hard in the parent loess rock Ck.

Surface horizons were characterized by granular and subangular blocky structure with a predominance of granular peds in horizon A1 and subangular blocky structure in horizon A2. In subsoil, the dominant types of structure were angular blocky structure, prismatic, subangular prismatic, and subangular blocky structure.

In the A horizons, carbonate neoformation was not observed. The Bk1 horizons were medium carbonated by the intensity of carbonate effervescence; however, the neoformations as a morphological element were not found. The Bk2 horizons were highly carbonated, and morphologically, neoformations had the form of disperse powdery lime. The subsoil was highly carbonated with a significant share of powdery precipitates and soft concretions. The spots were irregular shaped; they had diffuse boundaries and various concentrations of calcite crystals – from the crystals slightly visible on the general background of the soil material to predominance of whitish color.

Biological activity was most pronounced in the intensive root growth of herbaceous and woody plant species, with signs of invertebrate and vertebrate life activity on the soil structure and pore space. Maximum root content of herbaceous plant species was observed in surface horizons A; their quantity decreased in Bk horizons, and in Ck horizons the roots occurred in small quantity. Roots of woody plant species were developed at full depth of soil profile under the plantations of *Robinia pseudoacacia* and *Quercus robur*. In horizons A, a significant part of granular aggregates was represented by earthworm and insect larvae casts. Against the background of a more compact texture of Bk horizons, life activity of invertebrates was evident as a system of holes, much of which were filled with casts and structureless material (pedotubules). Similar signs were observed in the subsoil horizons, but to a smaller extent.

Sites 1 and 3 were located in the zone of mole rats (*Spalax microphthalmus*) activity. Mole passages were found across the whole profile. Within the humus-accumulative horizons A, the mole passages were filled mainly with loess parent material; in the lower part of the profile, the passages were filled with dark-colored humic material. Bulk density in the mole passages varied depending on their age; but generally, this parameter was less than the density of the parent material in the enclosing horizons. The boundaries between the mole passages and the enclosing material were from sharp to diffuse.

Effect of forest plantations on aggregate size distribution in Chernozem

Soil aggregate size distribution is an important characteristic closely related to the soil organic carbon content (Chaplot, Cooper, 2015; Polláková et al., 2018; Six et al., 2004); therefore, it may serve as a specific indicator of the intensity and duration of forest plantations' effect on the soil (An et al., 2010; De Carvalho Silva Neto et al., 2016; Jiang et al., 2019; Zhang et al., 2018).

Results of the study showed that the aggregate fraction of size 2–1 mm was predominant in the layers of 0–20 and 20–40 cm of all soils studied. Moreover, the maximum content of such a fraction (25.5%) in the layer 0–20 cm was in chernozem under black locust plantation, and the minimum (20.0%) was found in chernozem under steppe vegetation (Fig. 2a). In the layer of 20–40 cm, the maximum content of 2–1 mm aggregate size fraction (26.2%) was

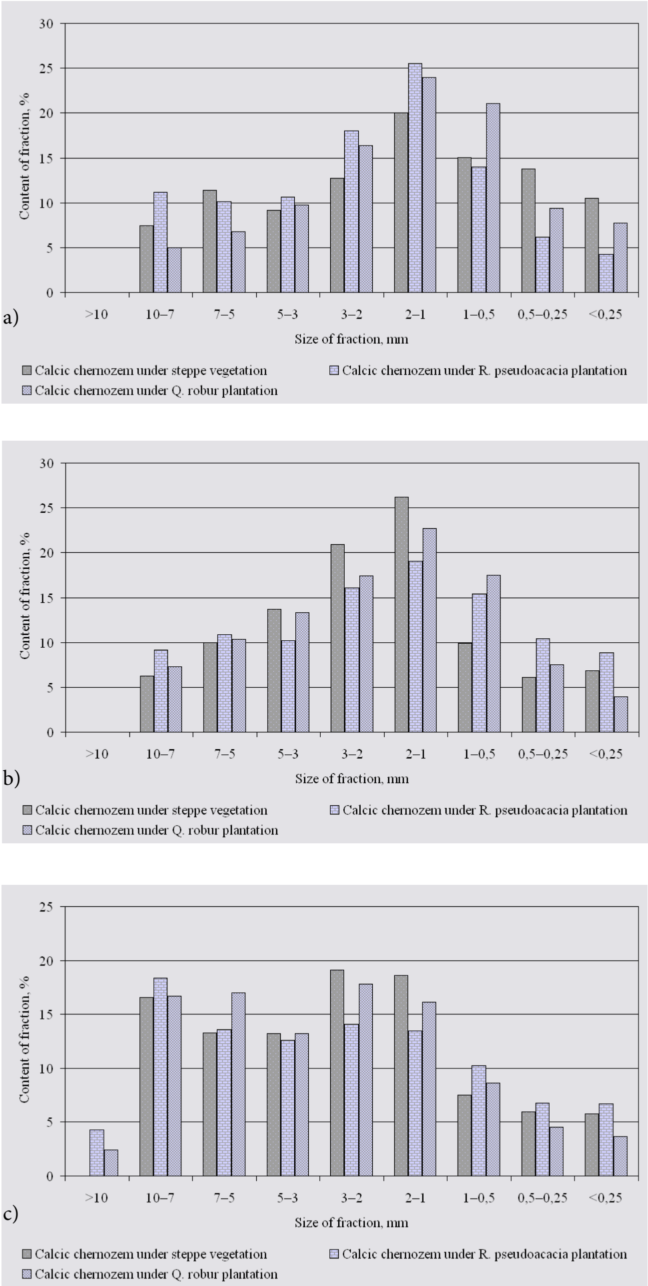

Fig. 2. Aggregate size distribution of the soils studied: a – horizon 0–20 cm; b – horizon 20–40 cm; c – horizon 40–60 cm.

found in chernozem under steppe vegetation and the minimum content (19.1%) of that was found in chernozem under black locust plantation (Fig. 2b). At a depth of 40–60 cm, aggregate fraction 3–2 mm predominated in chernozem under steppe vegetation (19.1%) and in chernozem under common oak plantation (17.8%) (Fig. 2c). In this depth of chernozem under black locust plantation, 10–7 mm aggregate fraction dominated (18.4%). Maximum contents of 10–7 mm aggregate fraction (17.9 and 28.1%, respectively) were found in the layer of 60–80 cm in chernozem under black locust and common oak plantations (Fig. 2d). In the same layer of chernozem under steppe vegetation, 7–5 mm aggregate fraction predominated (21.9%). Maximum contents of 10–7 mm aggregate size fraction (16.8 and 18.6%, respectively) were found in the layer of 80–100 cm in chernozem under black locust and common oak plantations (Fig. 2e). In the same layer of chernozem under steppe vegetation, 2–1 mm aggregate fraction predominated (24.0%). Additionally, in this soil, in all the selected layers, there was no agg-

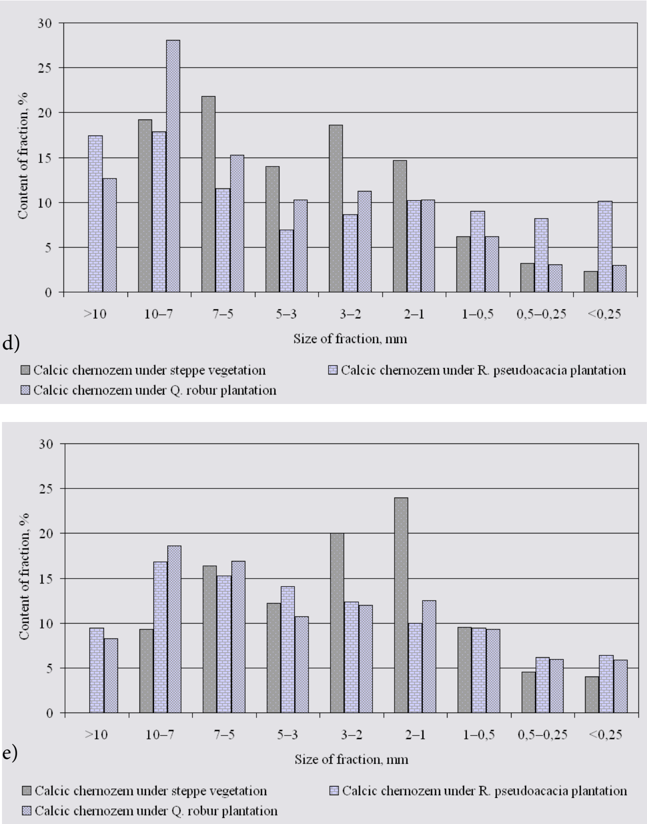

Fig. 2. Aggregate size distribution of the soils studied: d – horizon 60–80 cm; e – horizon 80–100 cm.

regate fraction >10 mm in size. In chernozems under black locust and oak plantations, this fraction was present in layers of 40–60, 60–80, and 80–100 cm.

The growth of *Robinia pseudoacacia* trees contributed to an increase (5%) in the content of 2–1 mm fraction units in the soil layer of 0–20 cm. Macroaggregates of fraction >10 mm were also present in chernozem under black locust plantation at a depth of 40–60, 60–80, and 80–100 cm; these macroaggregates were completely absent in chernozem profile under steppe vegetation. In these soil layers, increase in the content of aggregates 10–7 mm in size was present. Content of aggregates of the fraction <0.25 mm decreased with depth in chernozem under steppe vegetation and increased with depth in chernozem under black locust planting. The growth of *Quercus robur* trees also contributed to a certain increase (by 4%) in the content of aggregate fraction of 2–1 mm in chernozem at a depth 0–20 cm compared to chernozem under steppe vegetation. Macroaggregates of fraction >10 mm in size were also present in chernozem under common oak plantation at a depth of 40–60, 60–80, and 80–100 cm; these macroaggregates were completely absent in chernozem under steppe vegetation. Increase in the content of aggregates of 10–7 mm fraction was observed in 60–80 and 80–100 cm depth of chernozem under oak plantation. The content of aggregates of fraction <0.25 mm decreased with depth, as well as in chernozem under steppe vegetation.

Effect of forest plantations on the physical properties of chernozem

Gu et al. (2019) reported that the volume density values should be taken as one of the indicators to assess the effect of vegetation restoration process on the physical properties of the

T a b l e 2. Physical properties of the soils studied (x ± SD), n = 3.

Depth, cm	**Name of soil**		
	Calcic chernozem under steppe vegetation	**Calcic chernozem under *Robinia pseudoacacia* plantation**	**Calcic chernozem under *Quercus robur* plantation**
Bulk density, g/cm^3			
0–20	1.09 ± 0.038^{a}	1.25 ± 0.046^{ab}	1.18 ± 0.061^{a}
20–40	1.16 ± 0.031^{a}	1.35 ± 0.055^{ab}	1.25 ± 0.042^{a}
40–60	1.35 ± 0.051^{a}	1.42 ± 0.079^{a}	1.45 ± 0.047^{a}
60–80	1.54 ± 0.095^{a}	1.50 ± 0.057^{a}	1.52 ± 0.068^{a}
80–100	1.66 ± 0.040^{a}	1.61 ± 0.060^{a}	1.60 ± 0.071^{a}
Particle density, g/cm^3			
0–20	2.31 ± 0.113^{a}	2.45 ± 0.055^{a}	2.36 ± 0.072^{a}
20–40	2.42 ± 0.066^{a}	2.51 ± 0.089^{a}	2.48 ± 0.055^{a}
40–60	2.59 ± 0.056^{a}	2.58 ± 0.056^{a}	2.59 ± 0.046^{a}
60–80	2.63 ± 0.057^{a}	2.65 ± 0.035^{a}	2.67 ± 0.096^{a}
80–100	2.66 ± 0.036^{a}	2.68 ± 0.066^{a}	2.69 ± 0.090^{a}
Total porosity, %			
0–20	52.6 ± 1.77^{a}	48.9 ± 2.71^{a}	50.0 ± 2.59^{a}
20–40	52.2 ± 1.60^{a}	46.0 ± 3.24^{a}	49.5 ± 2.80^{a}
40–60	48.0 ± 3.05^{a}	45.0 ± 2.13^{a}	44.1 ± 2.07^{a}
60–80	41.5 ± 4.21^{a}	43.3 ± 2.87^{a}	42.9 ± 4.01^{a}
80–100	37.6 ± 1.93^{a}	40.0 ± 3.69^{a}	40.7 ± 2.86^{a}

Notes: different letters denote the sets within the indicator range that differ significantly from each other according to the results of the Tukey test with Bonferroni correction; differences between the sets were considered significant at $p < 0.05$; SD – standard deviation.

soil. This is explained by the fact that even a slight increase in soil density has a significant negative effect on the growth and development of tree species, particularly oaks (Bejarano et al., 2010; Cambi et al., 2018; Kormanek et al., 2015).

The lowest values of density and particle density (1.09 and 2.31 g/cm^3) at a depth of 0–20 cm were common in chernozem under steppe vegetation and the maximum values (1.25 and 2.45 g/cm^3) in chernozem under black locust planting (Table 2). As expected, the maximum value of total porosity (52.6%) was observed in chernozem under steppe vegetation and the minimum value (48.9%) in chernozem under black locust planting. According to these values, the content of chernozem under oak plantation was average between chernozem under steppe vegetation and chernozem under black locust plantation. At a depth of 20–40 cm, the lowest values of density and particle density and the maximum value of total porosity were found in chernozem under steppe vegetation. In this depth, as in the depth of 0–20 cm, the maximum values of density and particle density and minimum value of total porosity were characteristic of chernozem under black locust plantation. At the same time, significant differences in the layers of 0–20 and 20–40 cm were found only between the values of density of chernozem under steppe vegetation and chernozem under black locust plantation. At a depth of 40–60 cm, the minimum value of density (1.35 g/cm^3) and the maximum total porosity value (48.0%) were also found in chernozem under steppe vegetation, while the studied soils did not differ in terms of particle density values. In the layer of 60–80 cm, the maximum density value (1.54 g/cm^3) was found in chernozem under steppe vegetation and the minimum density value (1.50 g/cm^3) in chernozem under black locust plantation. Maximum value of particle density (2.67 g/cm^3) in this layer was found in chernozem under common oak plantation. Maximum density and minimum total porosity (1.54 g/cm^3 and 41.5%, respectively) were observed under the steppe vegetation. A sharp increase in density was observed in the layer of 80–100 cm, the maximum value of which (1.66 g/cm^3) was found in chernozem under steppe vegetation. The maximum values of particle density were found in chernozem under black locust plantation and oak plantation. The maximum value of total porosity (40.7%) was observed in chernozem under oak plantation.

In general, increase in density and particle density values with a regular decrease in total porosity values of the lower layers was observed in the soil studied, which is explained by a decrease in organic carbon content with depth and, as a consequence, by deterioration in the structural and aggregate composition (Li, Shao, 2006; Li et al., 2012).

The soils studied had no significant decrease in density and increase in total porosity of chernozem under steppe vegetation as a result of the influence of *Robinia pseudoacacia* and *Quercus robur* plantations, which is not entirely consistent with the results obtained by other authors (Jiao et al., 2011; Li et al., 2012; Zhang Q. et al., 2017; Zhang X. et al., 2018). This fact can be explained by the reason that initially, the plantings were set on fairly fertile soil rather than eroded one, as pointed out by the above-mentioned authors. Significant reduction in the abundance of herbaceous vegetation under *Robinia pseudoacacia* plantation and especially under *Quercus robur* plantation was another factor that could contribute to some increase in density and decrease in total porosity. It should be noted that all the soils studied are characterized by physical properties favorable for the growth and development of woody and herbaceous plants.

Effect of forest plantations on soil chemical properties and nutrient content

Within 0–20 cm depth, the maximum content of soil organic carbon (2.11%) was found in chernozem under common oak planting and the minimum (1.35%) in chernozem under black locust planting (Table 3). Maximum cation exchange capacity (44.98 cmol/100 g) was observed in chernozem under steppe vegetation and minimum (29.55 cmol/100 g) in chernozem under black locust plantation. Chernozem under steppe vegetation and chernozem under black locust plantation were characterized by a higher pH value compared with chernozem under common oak plantation, which can be explained by the release of organic acids during oak litter decomposition. This also explains the maximum value of hydrolytic soil acidity in chernozem under common oak plantation and its minimum value in chernozem under steppe vegetation. Chernozem under steppe vegetation and chernozem under black locust plantation were significantly different with lesser dry residue values compared with chernozem under common oak plantation, which can be explained by the increased ability of oak to capture and precipitate pulverous particles from the air that are released by steppe soil erosion, compared to black locust and steppe vegetation that have lesser ability to retain the dust.

Table 3. Chemical properties of the soils studied (x ± SD).

Depth, cm	**Name of soil**		
	Calcic chernozem under steppe vegetation	**Calcic chernozem under *Robinia pseudoacacia* plantation**	**Calcic chernozem under *Quercus robur* plantation**
Soil organic carbon, %			
0–20	2.03 ± 0.084^{a}	1.35 ± 0.067^{b}	2.11 ± 0.064^{a}
20–40	1.49 ± 0.057^{a}	0.70 ± 0.047^{b}	2.04 ± 0.072^{c}
40–60	0.59 ± 0.059^{a}	0.33 ± 0.056^{b}	1.18 ± 0.068^{c}
60–80	0.31 ± 0.051^{a}	0.20 ± 0.040^{a}	0.54 ± 0.046^{b}
80–100	0.27 ± 0.047^{a}	0.16 ± 0.050^{a}	0.26 ± 0.052^{a}
Cation exchange capacity, cmol/100 g			
0–20	44.98 ± 3.391^{a}	29.55 ± 3.869^{a}	36.51 ± 3.183^{ab}
20–40	35.85 ± 2.458^{a}	28.69 ± 3.097^{a}	31.54 ± 3.491^{a}
40–60	26.57 ± 2.234^{a}	23.94 ± 2.547^{a}	42.21 ± 3.269^{b}
60–80	30.00 ± 2.310^{a}	19.20 ± 2.560^{b}	21.40 ± 3.350^{ab}
80–100	34.89 ± 2.002^{a}	15.43 ± 2.844^{b}	40.28 ± 2.449^{a}
pH (H_2O)			
0–20	7.65 ± 0.122^{a}	7.64 ± 0.159^{a}	7.23 ± 0.146^{a}
20–40	7.67 ± 0.098^{a}	7.74 ± 0.137^{a}	7.16 ± 0.114^{b}
40–60	7.94 ± 0.061^{a}	7.80 ± 0.110^{a}	7.53 ± 0.363^{a}
60–80	8.07 ± 0.053^{a}	7.83 ± 0.071^{b}	7.97 ± 0.097^{ab}
80–100	8.26 ± 0.103^{a}	7.85 ± 0.119^{b}	8.15 ± 0.091^{ab}
Hydrolytic soil acidity, mmol/100g			
0–20	0.20 ± 0.046^{a}	0.24 ± 0.040^{a}	0.55 ± 0.038^{b}
20–40	0.13 ± 0.021^{a}	0.20 ± 0.026^{a}	0.64 ± 0.067^{b}
40–60	0.08 ± 0.032^{a}	0.14 ± 0.031^{a}	0.44 ± 0.047^{b}
60–80	0.07 ± 0.026^{a}	0.11 ± 0.021^{a}	0.29 ± 0.025^{b}
80–100	0.05 ± 0.031^{a}	0.08 ± 0.015^{a}	0.16 ± 0.035^{a}
Dry residue, ppm			
0–20	34.43 ± 2.050^{a}	37.79 ± 2.606^{a}	50.05 ± 2.734^{b}
20–40	29.90 ± 3.017^{a}	29.20 ± 2.096^{a}	46.00 ± 2.234^{b}
40–60	35.30 ± 2.252^{a}	30.64 ± 2.262^{a}	47.83 ± 3.669^{b}
60–80	35.81 ± 2.388^{a}	27.43 ± 2.538^{b}	58.83 ± 3.320^{c}
80–100	36.07 ± 2.268^{a}	25.17 ± 2.686^{b}	68.03 ± 3.900^{c}

Notes: different letters denote the sets within the indicator range that differ significantly from each other according to the results of the Tukey test with Bonferroni correction; differences between the sets were considered significant at $p < 0.05$; SD – standard deviation.

At a depth of 20–40 cm, values of carbon content in chernozem under the common oak stands were significantly the highest, while the minimum content of carbon was in chernozem under the black locust plantation. The maximum value of cation exchange capacity (35.85 cmol/100 g) was found in chernozem under steppe vegetation and the minimum value (28.69 cmol/100 g) of that was found under the black locust plantation. Significant decrease in pH values was observed in chernozem under common oak plantation in com-

Table 4. Content ($NH_4 + NO_3$; P_2O_5; K_2O) of nitrogen, phosphorus, and potassium in the soil studied (x ± SD), n = 3.

Depth, cm	**Name of soil**		
	Calcic chernozem under steppe vegetation	**Calcic chernozem under *Robinia pseudoacacia* plantation**	**Calcic chernozem under *Quercus robur* plantation**
N, mg/kg			
0–20	75.24 ± 3.042^{a}	60.73 ± 2.702^{b}	74.96 ± 3.046^{a}
20–40	47.28 ± 3.874^{a}	32.63 ± 2.550^{b}	69.91 ± 2.628^{c}
40–60	15.63 ± 2.510^{a}	21.88 ± 1.675^{a}	44.68 ± 2.123^{b}
60–80	9.67 ± 3.215^{a}	17.35 ± 2.145^{a}	15.48 ± 1.115^{a}
80–100	6.87 ± 1.054^{a}	14.18 ± 1.509^{b}	8.41 ± 1.039^{a}
P, mg/kg			
0–20	45.70 ± 2.696^{a}	25.64 ± 2.758^{b}	49.20 ± 2.342^{a}
20–40	39.54 ± 2.342^{a}	29.13 ± 1.946^{b}	63.39 ± 2.093^{c}
40–60	37.17 ± 2.228^{a}	38.07 ± 2.663^{a}	62.18 ± 1.487^{b}
60–80	37.83 ± 1.938^{a}	38.27 ± 2.197^{a}	51.44 ± 1.448^{b}
80–100	38.21 ± 2.909^{a}	38.14 ± 1.642^{a}	50.68 ± 1.997^{b}
K, mg/kg			
0–20	138.52 ± 3.259^{a}	107.19 ± 4.052^{b}	98.03 ± 2.312^{b}
20–40	83.85 ± 2.303^{a}	59.37 ± 2.587^{b}	62.68 ± 2.871^{b}
40–60	79.52 ± 2.477^{a}	54.62 ± 3.293^{b}	79.03 ± 3.257^{a}
60–80	75.09 ± 3.070^{a}	60.26 ± 2.422^{b}	64.92 ± 2.875^{b}
80–100	72.25 ± 2.394^{a}	69.64 ± 3.325^{a}	70.03 ± 2.345^{a}

Notes: different letters denote the sets within the indicator range that differ significantly from each other according to the results of the Tukey test with Bonferroni correction; differences between the sets were considered significant at $p < 0.05$;SD – standard deviation.

parison with chernozem under steppe vegetation and chernozem under black locust plantation. Also, chernozem under common oak plantation was characterized by large values of hydrolytic soil acidity and dry residue compared to chernozem under steppe vegetation and chernozem under black locust plantation.

The maximum values of soil organic carbon content (1.18%), cation exchange capacity (42.21 cmol/100 g), hydrolytic soil acidity (0.44 mmol/100 g), and dry residue (47.83 ppm) in chernozem under oak plantation were obtained at a depth of 40–60 cm. The maximum pH value (7.94) was characteristic of chernozem under steppe vegetation.

The maximum content of soil organic carbon was found at a depth of 80–100 cm in chernozem under steppe vegetation and chernozem under common oak plantation (0.27 and 0.26%, respectively). Chernozem under steppe vegetation and chernozem under common oak plantation were also characterized by increased values of cation exchange capacity and pH compared with chernozem under black locust plantation. The maximum values of hydrolytic soil acidity (0.16 mmol/100 g) and dry residue (68.03 ppm) were found in chernozem under common oak plantation.

In general, growth of common oak has a more pronounced positive effect on the chemical properties of chernozem than the growth of black locust. This is manifested by a slight

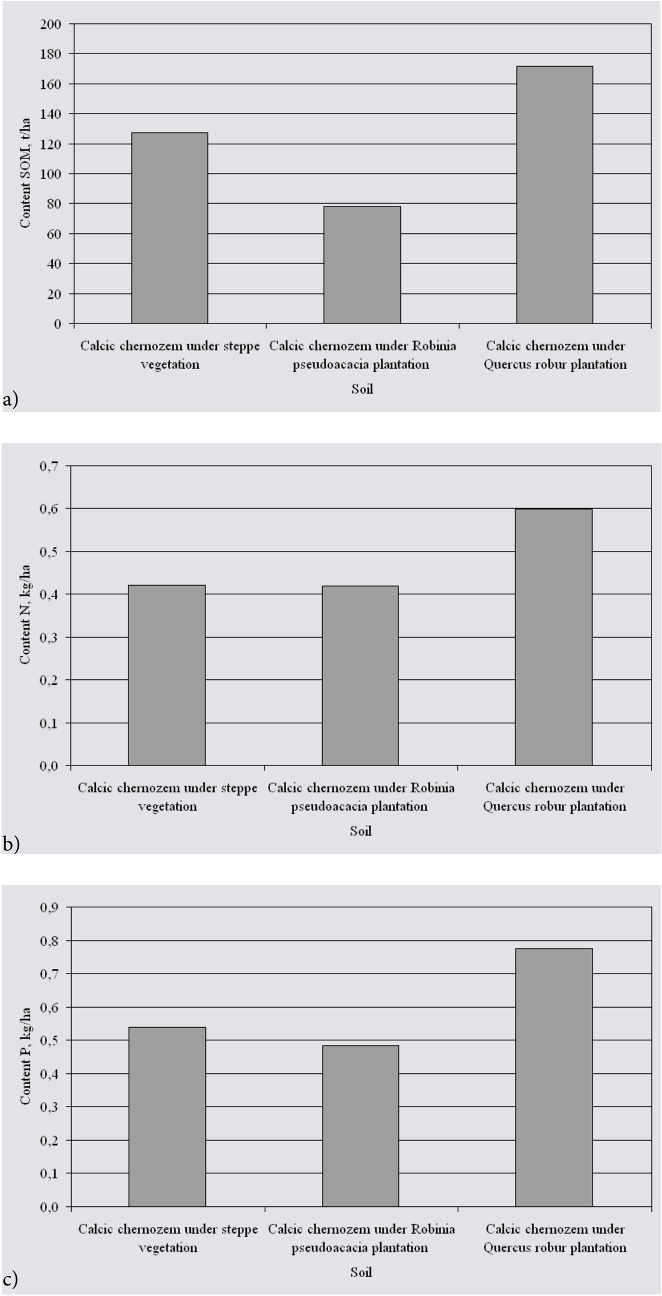

Fig. 3. Stocks of carbon (a), nitrogen (b), phosphorus (c) in the 1-m layer of the soil studied.

increase in organic carbon content and an increase in cation exchange capacity of chernozem under common oak plantation compared to chernozem under steppe vegetation and chernozem under black locust plantation.

When studying the effect of black locust and oak plantings on the nutrient content in chernozem, it emerged that at a depth of 0–20 cm, the greatest nitrogen and phosphorus reserves were found in chernozem under steppe vegetation and chernozem under oak plantation (Table 4). In chernozem under black locust plantation, the contents of nitrogen and phosphorus were significantly minimal (60.7 and 25.64 mg/kg, respectively). Maximum potassium content (138.52 mg/kg) was found in chernozem under steppe vegetation and the minimum content (98.03 mg/kg) was found in chernozem under oak plantation.

At a depth of 20–40 cm, the maximum contents of nitrogen and phosphorus (69.91 and 63.39 mg/kg) were found in chernozem under oak plantation and the minimum contents (32.63 and 29.13 mg/kg) were found

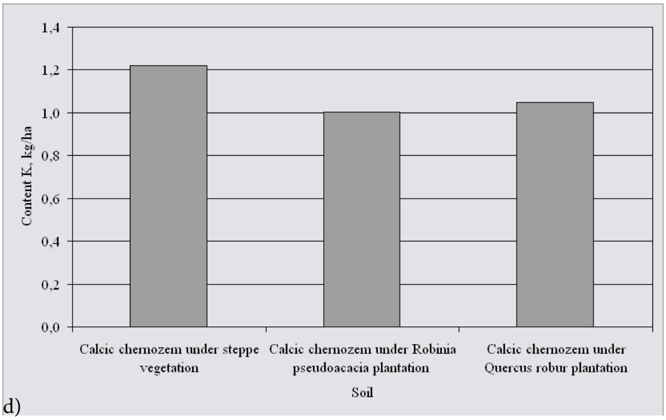

Fig. 3. Stocks of potassium (d) in the 1-m layer of the soil studied.

in chernozem under black locust plantation. As in 0–20 cm depth, significant maximum reserves of potassium were found in chernozem under steppe vegetation.

As in previous layers, the largest nitrogen and phosphorus reserves were found at a depth of 40–60 cm in chernozem under oak plantation (44.68 and 62.18 mg/kg, respectively). The minimum values of this nutrient content in this soil layer were found in chernozem under steppe vegetation and somewhat more values were found in chernozem under black locust plantation. In this depth, the maximum potassium content was observed in chernozem under steppe vegetation and chernozem under oak plantation (79.03 and 79.52 mg/kg, respectively).

The nutrient distribution was similar at depths of 60–80 and 80–100 cm. The maximum nitrogen content was found in chernozem under black locust plantation and the minimum nitrogen content in chernozem under steppe vegetation. The highest values of phosphorus were associated with chernozem under common oak plantation and the lowest values were observed in chernozem under steppe vegetation and chernozem under black locust plantation. The maximum potassium deposits were found in chernozem under steppe vegetation.

For clarification the behavior of carbon, nitrogen, phosphorus, and potassium accumulation under the influence of *Robinia pseudoacacia* and *Quercus robur* plantations, storages of these nutrients were calculated by soil layers 10 and 100 cm in thickness.

Within the 10-cm layer, the maximum reserves of carbon, nitrogen, and phosphorus (24.9 t/ha, 0.088 kg/ha, and 0.058 kg/ha, respectively) were found in chernozem under *Q. robur*, slightly less (22.2 t/ha, 0.082 kg/ha, and 0.050 kg/ha, respectively) reserves in chernozem under steppe vegetation, and the least reserves (16.8 t/ha, 0.076 kg/ha, and 0.032 kg/ha, respectively) were found in chernozem under *Robinia pseudoacacia*. The maximum amount of potassium (0.151 kg/ha) was detected in chernozem under steppe vegetation, lesser (0.134 kg/ha) amount in chernozem under *R. pseudoacacia* plantation, and the minimum (0.116 kg/ha) of that was found in chernozem under *Quercus robur* plantation.

At a depth of 100 cm, the highest carbon content (171.7 t/ha) was found in chernozem under *Q. robur* plantation and the minimum content (78.0 t/ha) was detected in chernozem under *Robinia pseudoacacia* plantation. Chernozem under steppe vegetation occupied an intermediate position in terms of carbon deposit values (Fig. 3a). The maximum contents of nitrogen (0.598 kg/ha) as well as carbon were found in chernozem under *Quercus robur* plantation (Fig. 3b).

The values of nitrogen deposit in chernozem under steppe vegetation were similar to those in chernozem under *Robinia pseudoacacia* plantation (0.421 and 0.419 kg/ha, respectively). The maximum reserve of phosphorus (0.775 kg/ha) was found in chernozem under *Quercus robur* plantation (Fig. 3c) and the minimum reserve (0.483 kg/ha) in chernozem under *Robinia pseudoacacia* plantation. Chernozem under steppe vegetation occupied an intermediate position regarding the values of phosphorus deposits. Maximum potassium content (1.222 kg/ha) was detected in chernozem under steppe vegetation (Fig. 3d). Chernozems under *Quercus robur* and *Robinia pseudoacacia* plantations were characterized by slightly smaller reserves of potassium (1.049 and 1.002 kg/ha, respectively) compared with chernozems under steppe vegetation.

Conclusion

The effect of *R. pseudoacacia* and *Quercus robur* plantations on aggregate size distribution of chernozem was evident in the increase in content of aggregate fraction of 2–1 mm and in formation of aggregate fraction >10 mm, which were absent in chernozem under steppe vegetation. The changes in the physical properties of chernozem were evidenced by a slight increase in their density and particle density, as well as a decrease in total porosity, but these differences were more pronounced in the upper layers of chernozem under *Robinia pseudoacacia* plantation than in chernozem under *Quercus robur* plantation. Changes in the chemical properties of chernozem were associated with a decrease in carbon content under the growth of *Robinia pseudoacacia* and an increase in carbon content under the growth of *Quercus robur*. Effect of plantations' growth on the value of cation exchange capacity was manifested in the same manner. The growth of *Robinia pseudoacacia* and *Quercus robur* plantations was accompanied by a certain decrease in pH level, increase in hydrolytic soil acidity, and dry residue of chernozem. Effect of *Robinia pseudoacacia* planting was pronounced as evidence by a decrease in carbon, nitrogen, and phosphorus content in chernozem. By contrast, the influence of *Quercus robur* growth led to accumulation of these nutrients. Growth of *Robinia pseudoacacia* and *Quercus robur* plantations led to a decrease in potassium reserves in chernozem, which may indicate its active uptake by these woody species. In general, *Q. robur* planting is characterized by a large positive effect on the physical and chemical properties of chernozem than *Robinia pseudoacacia* planting. The findings obtained serve as a ground for making a recommendation for growing *Q. robur* plantations in the conditions of the steppe zone of Ukraine in order to improve the zonal chernozems' state and fertility.

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FUNCTIONALITY OF THE ECOLOGICAL NETWORK ELEMENTS FROM THE POINT OF VIEW OF MAMMAL MIGRATIONS IN THE CONTACT ZONE OF THE FOREST AND AGRICULTURAL LANDSCAPE

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Abstract

Nevřelová M., Novota M.: Functionality of the ecological network elements from the point of view of mammal migrations in the contact zone of the forest and agricultural landscape. Ekológia (Bratislava), Vol. 39, No. 1, p. 45–57, 2020.

The aim of the research was to verify the functionality of the ecological network elements from the point of view of wildlife mammal migrations in the observed territory. Theoretical basis defines fragmentation of the landscape, the migrations of forest animals, ecological networks, and their connectivity. In the research territory, species such as *Capreolus capreolus, Cervus elaphus, Sus scrofa, Vulpes vulpes, Castor fiber* and *Lepus europaeus* were recognized. The result of the issue is the confirmation or reversal of the functionality of the ecological network elements of the forest animal migrations and the actual status in the observed area. In the contact areas of the Small Carpathians forests and the lowland areas, the research was carried out during 2015, 2016, and 2017. The results have shown that the game tends to migrate between the Small Carpathian forests and the adjacent lowland, but the migration potential is very limited because of the presence of strong migration barriers. Biocenters located in the monitored area provide a variety of conditions and are widely used by almost all species, and we consider them to be functional in terms of game migration. Biocorridors are problematic, whose functionality with regard to the migration of wildlife is considerably limited because of the location of the D2 highway and first- and second-class roads.

Key words: mammals, migrations, Ecological Network, connectivity, fragmentation.

Introduction

Anthropogenic activity creates barriers in the landscape that reduce and isolate habitats, threaten biodiversity, and reduce land connectivity. Fragmentation negatively affects the nature of the landscape and the wildlife populations.

Fragmentation means the division process or the resulting state of distribution of natural areas, which can be characterized by a reduction in the size of natural areas, the formation of several smaller isolated fragments, and an increase in the degree of isolation, which can be further multiplied by different types of barriers (Ružičková et al., 2011).

Migratory barriers are the natural and anthropogenic structures in the landscape that hinder the free movement of animals. Basic types of landscape barriers are roads and highways, railways, watercourses and water areas, fences, settlement infrastructure, and inappropriate habitats (areas of an adverse environment for a particular species; Anděl et al., 2010).

The most serious fragmentation effect is related to land communications, because they create long lines in the landscape that cannot mislead the animals in any way (Romportl et al., 2009). Particularly highly trafficable communications are an insurmountable barrier to the migration of many species.

According to Anděl et al. (2010), unsuitable habitats are an obstacle to the movement of animals in the country. For large mammals that predominantly inhabit the forests, treeless landscape is an inappropriate biotope and migratory barrier.

We need to look at migration barriers not only in terms of their individual direct effect in a given location but also in terms of their accumulation in a certain space and the passage of the country as a whole. A country with a dense network of migratory barriers becomes difficult to pass even if individual barriers do not themselves have a limiting character (Anděl et al., 2010).

To preserve the connectivity of migrating suitable landscape features, it is important to ensure the passage of anthropogenic barriers in the country. In particular, the line elements form an impenetrable barrier in the landscape. According to Klescht and Valachovič (2002), the impact of transport on animals can be mitigated by the construction of passageways and other protective measures. The game does not have the ability to bypass road traffic and is forced to use artificially created passes that are often not attractive to the crew and thus reduce their efficiency.

Demands of the mammal species for migrations

Reduction, isolation to loss of natural habitats, and reduction of movement of organisms in the landscape lead to weakening, to the extreme extent, to the extinction of sensitive species. The division and reduction of habitats (fragmentation) are primarily influenced by those species of animals that inhabit a larger area with a relatively small number of individuals. On the basis of the similar properties and migration claims, we can, according to Anděl et al. (2005), divide the species of mammal into three categories:

- Large mammals and species migrating widely across borders and across Europe. Long-distance migrations within one country to the whole of Europe are typical of some large mammals, such as the red deer (*Cervus elaphus*), Eurasian lynx (*Lynx lynx*), brown bear (*Ursus arctos*), grey wolf (*Canis lupus*), wildcat (*Felis silvestris*), moose (*Alces alces*), and so on. This group of species is also very sensitive to the reduction of habitats and obstacles to migratory routes, which should form a transitional landscape with suitable habitat types (forestry, rapeseed, and pasture communities).
- Medium-sized mammals and species migrating to shorter distances, or local migrations for food, water, and relaxing spots. Some ungulates are included in this group: roe deer (*Capreolus capreolus*), wild boar (*Sus scrofa*), fallow deer (*Dama dama*), and so on. For these species, the importance of migrating young individuals is important when they

become independent and looking for a new territory. Local migration for food, water, and resting places is also very important.

- Medium-sized mammals and carnivores migrating to food at local level. A group of medium-sized mammals and carnivores represent species such as red fox (*Vulpes vulpes*), European badger (*Meles meles*), Eurasian otter (*Lutra lutra*), Eurasian beaver (*Castor fiber*), pine marten *(Martes martes*), beech marten (*M. foina*), and least weasel (*Mustela nivalis*).

In a mosaic landscape, the structure of the landscape and the extent of its fragmentation are determined by the anthropogenic activity for the success of migrations (Romportl et al., 2009). Natural barriers, for example, the absence of forests, force forestry animals to move through the landscape to overcome the free spaces that they mostly avoid instinctively (Anděl et al., 2010).

The degree of the barrier width of the stream has an effect on the species diversity and equitability of the communities of the watercourse banks. The terrestrial mobility of individual in small terrestrial communities, in the segment where they are trapped, increases in relationship with the width of stream (Bohdal et al., 2016).

A strategy to compensate loss is migration to lower altitudes during the winter and, above all, toward upper altitudes during summer. The triggering mechanism of downhill migration is considered to be 20–25 cm of continuous snow cover (Schmitd, Gossow, 1991).

Partial migration, out of Slovakia, has been reported for all native forest deer species in Scandinavia, both for a small browser, the roe deer *Capreolus capreolus* (Mysterud, 1999), a large browser, the moose *Alces alces* (Ball et al., 2001), as well as for the mixed feeder, the red deer *Cervus elaphus* (Albon, Langvatn, 1992). Although this has been reported in many single populations, there have been few studies quantifying variation in partial migration between populations for a given species (Mysterud et al., 2011).

Migrating individuals overcome the transition from winter to summer (and vice versa) significant distances. Roe deer (*Capreolus capreolus*), fallow deer (*Dama dama*), wild boar (*Sus scrofa*), and red deer (*Cervus elaphus*) are the flagship game species in Slovakia (Kropil et al., 2015).

In Slovakia, *C. elaphus* observed mountainous areas and floodplain forests near the river Danube. *C. elaphus* belongs to our most widespread and most productive game and to migrants traveling for long distances up to 100 km (Völk, Reiss-Enz, 2009).

For the Alpine-Carpathian Corridor project, this species was chosen as an indicator species for studying the extent of the landscape continuity. It is sensitive to the effects of fragmentation in the region, needs space, shows migration behavior, and has high habitat requirements. Ecological requirements of *C. elaphus* agree with the requirements of several forest animal species; therefore, *C. elaphus* is a suitable indicator of habitat fragmentation and disruption (Egger et al., 2012).

The roe deer, *Capreolus capreolus*, is one of the foremost examples of behavioral flexibility among ungulates. This species has increased rapidly in range from its original forest-mosaic habitat into open agricultural plains. The primary habitat of the roe deer is forest clearings, hedges, and woodland edge (Hansson, 1994). Nevertheless, the roe deer has spread into open arable land and grassland, most noticeably in Eastern Europe (Kaluzinski, 1974; Hewison et al., 1998). In woodland habitat and arable-woodland mosaics, the roe deer live in association with woodland in a social unit that typically consists of less than five related individuals (Hewison et al., 1998). Open-plain populations aggregate in significantly larger groups, >50 individuals in several cases (Zedja, 1978; Bresiński, 1982; Mrlik, 1991; Gerard et al., 1995; Hewison et al., 1998).

The roe deer has two main resource requirements: (1) nutrient-rich forage and (2) cover, which offers escape from predators and disturbance (Putman, 1986; Cibien et al., 1995; Mysterud, Østbye, 1995, 1999; Tufto et al., 1996; San José et al., 1997; Mysterud, 1999).

According to Krištofík and Danko (2012), *C. capreolus* has not been so widespread in our past as it is today. Forest farmland is more suitable for it compared with extensive forest complexes, which in the past occupied a much larger area. The area under consideration is a suitable living space for it with a diverse range of landscape features. Open habitats, such as unused arable land and vineyards, are an appropriate biotope for *C. capreolus*, providing him with enough food.

Sus scrofa is found on most of our territory and mainly inhabits warm deciduous forests. It is most suitable for oak forests and agricultural landscapes.

Material and methods

Field research was conducted on a defined area in the contact zone of the mountain Small Carpathian and Záhorie lowland, particular in the territories of the Bratislava—Devínska Nová Ves, Záhorská Bystrica, and Stupava. The territory has been prepared by the local or regional ecological network and so it was possible to also evaluate the functionality of its elements.

The research was carried out in the time range from October 2015 to April 2017, and traces of game, the migration routes, and the occurrence of forest wildlife were recorded and the critical parts of the area from the point of view of migration were identified. Together with the mapping, the permeability of the individual elements of the ecological network for the forest beasts was validated. The occurrence of forest game and migratory routes were mapped and implemented simultaneously with the verification of the feasibility of the system elements of the ecological network. The occurrence of forest game animals was recorded based on the track records and the residential character (excrements, fur, and abrasions on the trees) and either spot or in the case of line formations traces.

The dimensions of the profile underpasses/sluices, other parameters of the regulation of water flow, converting a game to underpasses, and subsequently, the evaluated feasibility of these objects for specific groups of animals have also been recorded. Technical support of the migration permeability in places of road crossing and biocorridors is complicated by the flat nature of the area, where it is not possible to naturally bridge below lying valleys and it is necessary to choose expensive ecoducts. In some cases, there are sufficient smaller-pass water flows, but in the case of a small height difference between the roadway and the surrounding area cannot be build a large enough, in order to use by large mammals such as *Cervus elaphus*.

We only implemented measurement parameters and monitoring the incoming of game for the selected underpasses in the area, which then appear to be passable for forest animal and had the potential to serve as an alternative path.

Study area

Research area was divided into two parts: north and south. The northern part of the area is of a different nature from the southern part. In the northern part, forests stand areas are found in a greater number, which are interspersed with areas of arable land and permanent grass vestures, and this creates a more diverse mosaic of habitats. Transport infrastructure in the northern part is less dense and is used in a lesser extent. In the southern part, large areas of agricultural cultures, as well as industrial and business parks, are dominated and the road infrastructure is denser.

The eastern side of the study area borders with the append forest vegetation of the Small Carpathians, and in the south east, there is an important and very much used transport node (roads D2, no. 2, no. 505) that connects the Záhorská Bystrica and Devínska Nová Ves with the other parts of the Bratislava. Most of the research area is agricultural land further developed in the form of large constructions and objects (shopping centers and hypermarkets) and traffic roads, in addition, there are old abandoned orchards.

In the research area, the following protected areas and elements of ecological network are located:

- CHKP (protected landscape element) stream Vápenický potok (25,161 m^2) is declared to ensure the protection of the natural alder forests' vegetation growth in the riverbed, which performs the function as biocorridor. It is a part of the regional biocorridor (rBK) Stará mláka.
- Regional biocorridor (rBK) Stará Mláka is a network of water biocorridors along the stream Mláka and its tributaries (stream Vápenický potok, stream Lamačský potok, stream Dúbravský potok, water channel Antošov, stream Bystrický potok and stream Mariánsky potok) in the middle of intensively used arable land.
- Local biocorridor (mBK) Kamenáče is located in the center of rBK Stará Mláka and connects most of its branches; it is largely formed by arable land that is surrounded by bands of non-forest vegetation.
- Local biocenter (mBC) lake Devín covers the forest soil; the majority is *Robinia pseudoacacia* monoculture. Habitats with natural character are located in the southern part.
- Local biocorridor (mBK) Rakytná, where the majority of the territory consists of the oak-hornbeam and pine forest vegetation, but in the central and eastern part of the area, we can find the even older natural stands with the dominance of oak tree (*Quercus robur*); in this place, the flooded area lies, where the water regime regulates the beaver.
- Local biocorridor (mBK) stream Stupavský potok, where small protected area (national nature monument) stream Stupavský potok was designed in the framework of the landuse plan of the Stupava village (2012), which currently has the validity as regional biocorridor.

The most important site from the point of view of animal migrations in a radius of several kilometers from the borders of the area may be a potential goal or the starting point of wildlife migrations, which passes through the research area. On the territory of the river Morava, protected areas and elements of ecological network are declared: Ramsar locality Niva Moravy, the territory of European importance (ÚEV) River Morava, local biocenter (mBC) Morava, and biocorridor Dolná niva rieky Moravy with the trans-regional importance. The eastern and southern parts of the study area border the protected landscape area Small Carpathians, which is a part of regional biocenter (rBC) Hrubá pleš situated near the eastern border of the area, regional biocenter (rBC) Lingavy east from the Stupava city, and regional biocenter (rBC) Vrchná hora.

Results

In the research area, the occurrence of the species *Capreolus capreolus*, *Sus scrofa*, *Cervus elaphus*, *Vulpes vulpes*, *Castor fiber*, and *Lepus europaeus* was recorded (Table 1).

What concerns the migration of wild animals, the fundamental problem is found in the methodology of ecological network, which enables the interruption of the functional biocorridors by the barriers. For long distance migration of large mammals, however, such interruption of the biocorridor is fatal and basically means malfunction of the corridor. Thus, corridors in many cases do not cover them with the main animal migration routes of large mammals (Anděl et al., 2010).

Table 1. The occurrence of species within the ecological network (EN) elements.

Species EN elements	*Cervus elaphus*	*Capreolus capreolus*	*Sus scrofa*	*Vulpes vulpes*	*Castor fiber*	*Lepus europaeus*
rBK Stará mláka	–	+	+	+	+	+
rBK Stupavský potok	+	+	+	+	+	+
mBK Kamenáče	–	+	+	+	–	+
mBC Devínske jazero	+	+	–	+	–	+
rBC Rakytná	+	+	+	+	+	+

In the area of the old orchards between roads (from the west D2 highway, from the east road no. 2), numerous tracks of species *Capreolus capreolus* and *Sus. scrofa* were recorded, which shows that the wildlife in these areas often exceeds the first-class road no. 2.

Overgrown meadows lie on the western side of road no. 2 between the crematory area and Podkerepušky. This vegetation has the character of forest grasslands with the species such as *Pinus sylvestris* and *Quercus* sp. together with grasslands and shrubland communities. In these places, we found numerous tracks of game (*Capreolus capreolus, Sus scrofa,* and *Cervus elaphus*), reflecting the adjacent location of the site with forests in the protected landscape area of Small Carpathians.

Local biocorridor (mBK) Hrubá pleš

The forested western slopes of the Small Carpathians (dominantly oak hornbeam primeval forests, preserved forests with a relatively natural composition and structure) are located to the east of the study area—there is an area in the ecological network categorized as local biocorridor Hrubá pleš and the game occurs here in large numbers. Multiple herds of the species *C. elaphus* were observed several times, and the activities of the other species of forest wildlife that often meet in the adjacent meadows, shrubs and abandoned orchards exceeding road no. 2 were also recorded.

Regional biocorridor (rBK) Stará mláka

Regional biocorridor Stará mláka consists of several parts (Fig. 1). The part L passes through the area where the main landscape element is stream Lamačský potok flowing from the Small

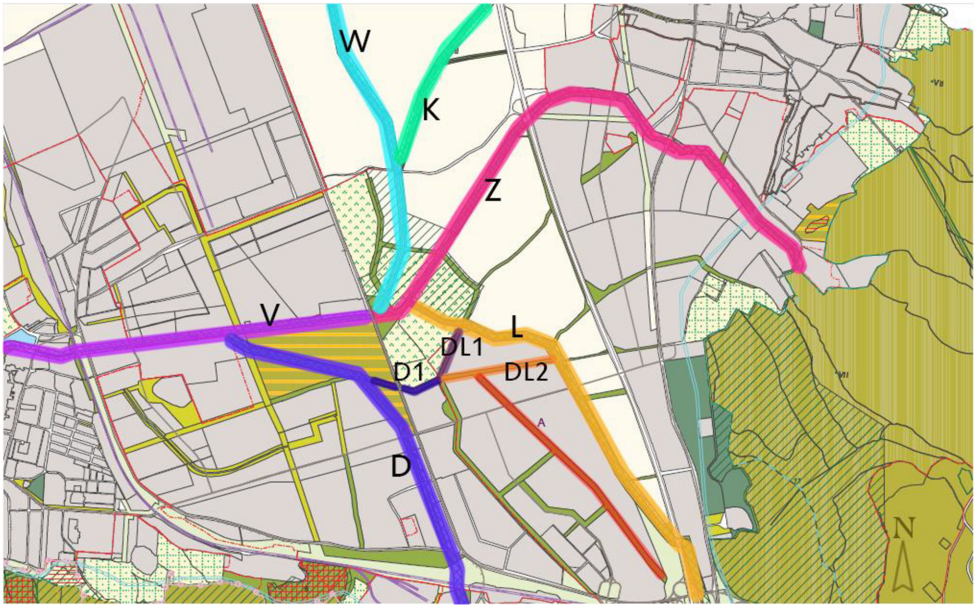

Fig. 1. Branches of biocorridor (rBK) Stará mláka (Sources: Aurex, 2010, modified by Novota, 2017).

Carpathians. The stream passes through the partially built-up area of the Lamač and subsequently crosses 3 frequented roads (road no. 2, no. 505, and D2 highway), where built construction was not present for the functional migration for animals; only a small sluice for water flow is present, and, therefore, the functionality of the biocorridor for forest beasts in this place are practically zero. Toward the northwest from the D2 highway, the stream flows through intensive agricultural used landscape and, together with its accompanying non-forest wood and shore vegetation, forms the biocorridor, the occurrence of the species *Sus scrofa, Capreolus capreolus,* and *Lepus europaeus* was confirmed on the territory.

The functionality of the part V for forest beasts is rather limited despite its high potential for migration, as this is the only biocorridor in the wider area, which has the potential to bring together a network of biocorridors in the southeastern part of the area with the western part—protected, ecologically significant areas in the Morava river floodplain.

The part D extends in parallel with road communication no. 505. In its northern part, multiple track types of species *Sus scrofa* and *Capreolus capreolus* were recorded, but in the southern part of this biocorridor, traces were not recorded. Probably, this biocorridor is not exploited by the game in the whole length, because of the cumulative effect of multiple barriers (buildings, fenced areas, and transport nodes).

The part Z follows the flow of the stream Vápenický potok flowing through the southern edge of the built-up area of the village of Záhorská Ves. There is a relatively well-preserved part of the alder forest, in which we recorded the presence of *C. capreolus.* The connectivity of biocorridor is further broken by the highway D2, under which the stream Vápenický potok runs through the sluice, which was built for water management purposes. In this place of the sluice, the parameters were measured to evaluate its permeability for wildlife. Traces of the species *Vulpes vulpes* were recorded directly in the sluice along the entire length.

Toward the west from the highway D2, biocorridor passes without interruption through the fields in the form of a narrow belt of non-forest vegetation up to the biocenter of local importance, which consists of agricultural area and area of permanent grassland, which is surrounded by a few linked elements of non-forest vegetation. In this area and in its close proximity, occurrence of individuals of the species *Capreolus capreolus* (40 individuals) was recorded frequently.

The part K has the branches K1 and K2, while to them the relevant streams flows under the highway D2 underpass PK1 and PK2. These are acceptable only for medium large size species of mammals and smaller animals. Using underpass, this group of animals confirms the finding of tracks and excrements of species *Vulpes vulpes.*

Another barrier that disrupts the connectivity of the biocorridor is the road no. 2, where this clash of roads is technically solved by a bridge built over the road over the stream Mariánsky potok. This recently built bridge/underpass P31 has the appropriate parameters and conditions for the migration of the C and D groups of animals. A fundamental difference from the other underpasses in the area lies in the sufficiently broad bank (3 m) on both sides of the flow with the natural surface (sand, clay). The evidence of underpass functionality for migration is the numerous findings of the feet of several species such as *Sus scrofa, Capreolus capreolus,* and *Vulpes vulpes* on both sides of the shore. This underpass is important precisely because it is the only migratory element in the area that allows the safe transfer of even the larger mammals through the road no. 2.

Local biocorridor (mBK) Kamenáče

Local biocorridor (mBK) Kamenáče is located in the place of confluence of the tributaries of the stream Mláka, in the middle of agricultural landscape. The greater part of it consists of arable land and permanent grass vegetation, which are after the edge protected by the line woody vegetation. This biocenter, as shown in the survey, has great importance for the forest animals, because *Capreolus capreolus* used it as winter habitat. During the winter months, numerous flock (40 individuals) have been observed to gather and graze in the surrounding fields. Close to this area, *Vulpes vulpes* and *Lepus europaeus* were also observed in a large number.

Regional biocenter (rBC) Rakytná

Regional biocenter (rBC) Rakytná (Fig. 2) includes several ecologically significant habitats for the animals. In the middle of the biocenter, the depression is located, through which runs the stream, and with the help of the building of the European beaver (*Castor fiber*) dam, a natural wetland with the occurrence of several rare species of flora and fauna was thus formed. Here, we founded here numerous nibble of the European beaver (*C. fiber*) and a high concentration of feet of the red deer (*Cervus elaphus*), which were regularly visually observed in numerous flock (12 individuals), and feet of the species *Vulpes vulpes*, *Capreolus capreolus*, and *Sus scrofa*. This biocenter is in links with the lake Devínske jazero.

Fig. 2. Regional biocenter (rBC) Rakytná (photo: Novota, 2017).

Local biocenter (mBC) lake Devínske jazero

Local biocenter lake Devínske jazero primarily consists of the black locust (*Robinia pseudoacacia*) and scots pine (*Pinus sylvestris*) monocultures. The species use this area for migration or for rest or shelter.

Regional biocorridor (rBK) stream Stupavský potok

The stream Stupavský potok is formed by the oak-hornbeam forest, which flows naturally part of stream Stupavský potok. Biocorridor includes important forest and aquatic habitats. Here we recorded the frequent occurrence of forest game. The feet across the stream (*Capreolus capreolus, Sus scrofa, Cervus elaphus*) have been abundant. We have found the stay characters of species *Sus scrofa* in a large number: staging space and residues of fur. The stream Stupavský potok provides suitable conditions for year-round occurrence of forest game and serves as a core area in the surrounding landscape.

Connectivity rBK stream Stupavský potok is disrupted by the highway D2, under which the stream flows through a constructed underpass/tunnel P102. Even though the underpass has big size profile, its length in proportion to the profile of the entrance is too big. The main problem is the lack of dry shore in a sufficient width, what deters animals from its use.

Biocenters located in the area provide diverse conditions and have been widely used by almost all species, and in terms of the migration of game, they are assessed as functional. Problematic were the corridors, whose functionality because of migration of forest animals is greatly limited because of the location of the highway D2 and road no. 2. These corridors are crossing the stream (rBK) Stupavský potok and most of them branches (rBK) Stará mláka and divided them into isolated sections. The conditions in the place of the crossing are not suit-

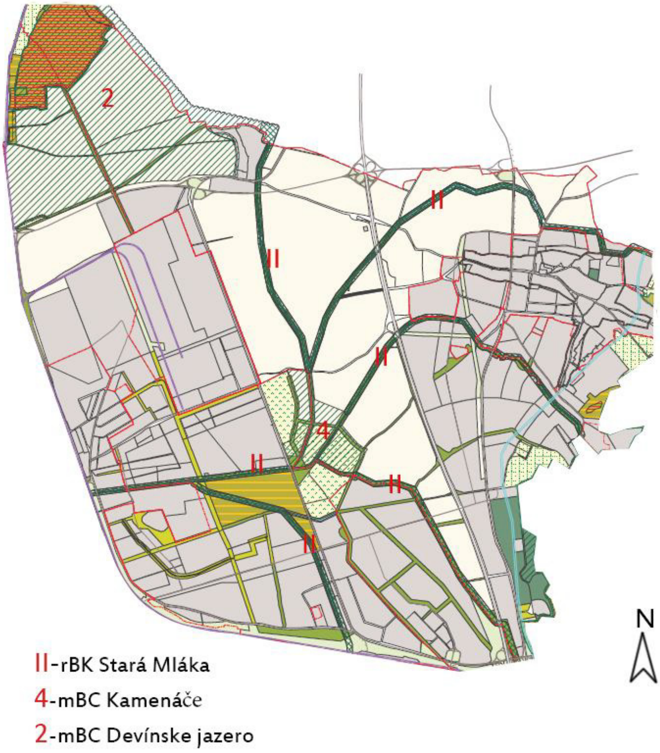

Fig. 3. Elements of the ecological network in the southern part of the studied area.

able for the transition of the migration species, and, therefore, there is no sufficient continuity between the Small Carpathians and the lowland Záhorská nížina for forest beasts (Fig. 3).

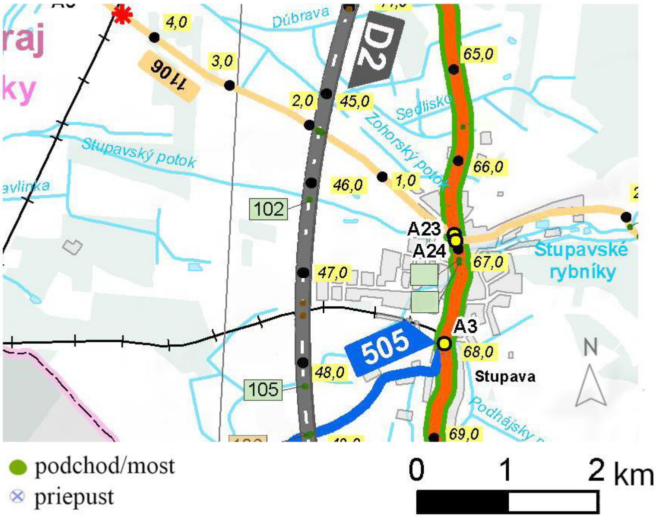

Fig. 4. Location of investigated underpasses (P 102 and P 105) under the D2 highway (northern part of the area) (Sources: http://wwww.cdb.sk, modified by Novota, 2017).

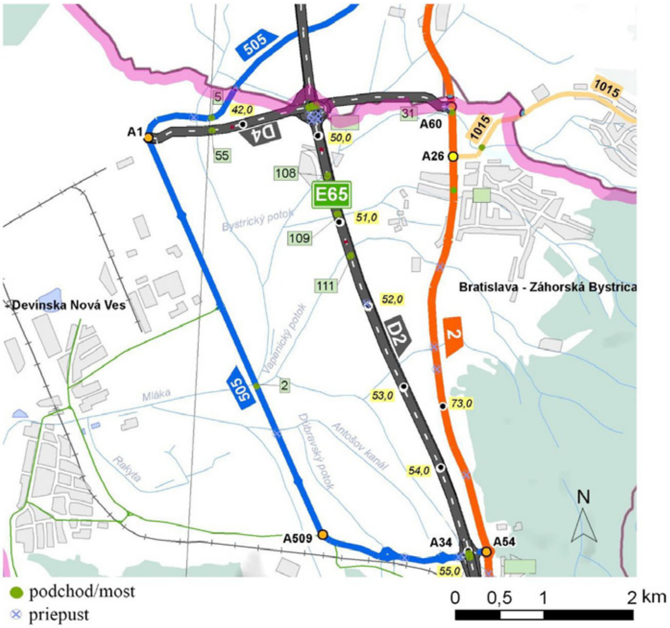

Fig. 5. Location of investigated underpasses under the D2 highway (P 108, P 109, and P 111), D4 highway—road no. 2 (P 31) and road no. 505 (P 2, P 5) (southern part of the area) (Sources: http://wwww.cdb.sk, modified by Novota, 2017).

Discussion

Romportl et al. (2009) assessed the elements that promote long-term sustainability migration in the landscape. It is appropriate to use the existing stable, legally protected elements and areas in the landscape, which are important for the long-term perspective of the protected corridor. Among the basic supporting elements that the map maker takes into account when defining the corridor are in particular ecological network—all elements, biocorridors, and biocenters of the supraregional and regional levels, elements of general nature and landscape conservation, large- and small-scale protected areas, and area of NATURA 2000.

The largest barrier, which divides the whole area, is the highway D2. Under the highway, underpasses that are used in particular for water management purposes are built. The usage of these objects for animal migrations was observed based on the selection of seven potential feasible underpasses and their parameters were compared with the reference recommended values of underpasses because of migratory requirements of the monitored species. Further evaluated underpasses were under road no. 2 and on the highway driving D4. It turns out that, neither underpass has appropriate parameters for animals of categories A and B. The three underpasses have appropriate parameters for animals in category C (Figs. 4 and 5).

Anděl et al. (2005) divided the target animal species into four categories in terms of their migratory claims. Species with long-distance line migration and the greatest demands during migration (*Cervus elaphus, Ursus arctos, Lynx lynx, Canis lupus, Alces alces, Felis sylvestris*) are in category A (large mammals); species with local migration for food, water, and rest and local populations well adapted to disturbing anthropogenic impacts (*Capreolus capreolus*, *Sus scrofa, Ovis musimon*, *Cervus dama*) are in category B (medium-sized mammals and ungulates); medium-sized mammals and small weasel beasts with local migration for food, water, and rest (*Vulpes vulpes, Meles meles, Lutra lutra, Lepus europaeus, Erinaceus concolor, Martes martes*) are in category C; and category D includes amphibians and reptiles.

The most used underpass for the wild animal migrations (*Cervus elaphus, Capreolus capreolus, Sus scrofa*) was underpass P31, which is located under the road no. 2 (Fig. 6). The fact that the parameters of the underpass profile do not have the minimal requirements of categories A and B and, nevertheless, are used by animals, we are attributing a sufficiently

Fig. 6. The most used underpass (P31) in the solved area (photo: Novota, 2017).

wide natural bank. Under the D2 highway, two underpasses P108 and P109 were used by *Vulpes vulpes* (Table 2).

Table 2. Parameters of underpasses under the highway D2, D4, and road no. 2 and no. 505 and the evaluation of their feasibility.

Underpass	Height of profile (m)	Width of profile (m)	Length of underpass (m)	Dry ashore (m)	Feasibility
P2	2.5	5	9		
P31	1.7	12	15	+ 3	C, D
P111	1.5	6.5	18		
P109	1.5	6	18		
P108	1.7	6.5	19	1	C, D
P105	1.6	4.5	17	0.4	
P102	6	5	25	0.4	
P5	1.2	1.7	8	1	D

Conclusion

Within a defined area with a strong impact of human activities, the main objective was to verify the functionality of the ecological network elements with regard to the migration of the forest animals.

In the study area, species such as *Capreolus capreolus, Cervus elaphus, Sus scrofa, Vulpes vulpes, Castor fiber*, and *Lepus europaeus* were recognized.

The results have shown that the game tends to migrate between the Small Carpathian forests and the adjacent lowland, but the migration potential is very limited because of the presence of strong migration barriers. It is necessary to complement the network of ecoducts over roads, especially in the places where the migrating game passes (highway D2, D4, roads no. 2, and no. 505). It would also be appropriate to implement technical modifications of the underpasses for increasing their functionality and attractiveness for the forestry.

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POPULATION DYNAMICS AND DISTRIBUTION PATTERNS OF DIURNAL RAPTORS IN NORTHEASTERN ALGERIA: SEASONAL VARIATION AND SOME NESTING CHARACTERISTICS

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Abstract

Elafri A., Boumaaza O., Khemis M.D.E., Boucherit K., Houhamdi M.: Population dynamics and distribution patterns of diurnal raptors in northeastern Algeria: seasonal variation and some nesting characteristics. Ekológia (Bratislava), Vol. 39, No. 1, p. 58–71, 2020.

Providing a live data monitoring of raptor abundances and spatial localization of their most important nesting areas is very helpful in building a strong future study and applying a sound strategy for effective safeguarding of these emblematic species. Using geographic information system (GIS) and global positioning system (GPS) techniques, we investigated spatial patterns of raptors distribution in the northeastern areas of Algeria during two consecutive breeding seasons (2014 and 2015). The total area sampled (31,000 km^2) host diverse raptor species (14 species), among them, the threatened species Egyptian vulture (*Neophron percnopterus*; 108 individuals and 19 active nests) and red-footed falcon (*Falco vespertinus*; 12individuals). The value of the region is attested by the presence of an abundant population of nesting black kite (*Milvus migrans*; 337 individuals). The large-scale spatial analyses of the studied region illustrate certain similarities in nesting habitat selection among raptors. Almost all species (90% of 209 nests detected) preferred to nest within multispecies assemblages (20 raptor assemblages found) and occupied altitudinal rocky cliffs across the inland region (semi-arid zones) rather than coastal region (sub-humid zones). Among all raptor species, exclusively, the common kestrel (*Falco tinnunculus*) is relatively synanthropic, because it was found to breed within cities (tolerate human activities). The raptor community in the coastal versus inland regions differed by 14%. The latter area seems to be more preferred in nest building, probably consequence of their semi-arid bioclimatic and landscapes characteristics, where high elevations and grasslands forming mosaics with Oak, Alpine, and Cedar forests are patchily distributed. The study is a first mapping database of important nesting sites dispatched across the northeastern areas of Algeria, and it can be effectively used in future complementary researches that aim to elucidate environmental factors that affect raptors life cycle.

Key words: raptor assemblages, cliff nesting, roadside point transect, inland regions, GIS.

Introduction

Raptors or "Bird of prey" refers to vulture, hawks, eagles, falcons, ospreys, and their allies; all of which are adapted for a lifestyle of aerial hunting (Ferguson-Less, Christie, 2001; Weidensaul, 1996). As organisms at the end of terrestrial food chains and aquatic food webs, these birds are both biologically important (i.e., important ecological role in controlling populations of rodents and other small mammals) and environmentally sensitive, which serves as a barometer of wild ecological health (i.e., indicators of worldwide pollution by pesticide; Weidensaul, 1996; Virani, Watson, 1998; Bildstein, 2006). They can also be used as "umbrella species" because their large home ranges and low nesting densities necessitate that any protected areas encompassing viable populations or complete communities protect sufficient habitat and populations of most, if not all, other species in the food web below them (Virani, Watson, 1998). Finally, an abundance and diversity of raptors invariably signals a largely undisturbed ecosystem (measure of our impact on landscapes, even in remote area), supporting an abundance of other wildlife (Weidensaul, 1996; Virani, Watson, 1998; Bildstein, 2006).

The population status and distribution of raptor species can be difficult to estimate because they are often dispersed and/or secretive species that nest in low densities (with large individual area needs), and their population can fluctuate cyclically in relation to prey abundance (Kirk, Hyslop, 1998). This can make raptors studies challenging, and many species remain poorly known around the word (Bildstein et al., 1998; Bierregaard, 1998; Watson, 1998). In the recent decades, raptors have become gradually more protected, and several species have becomes significant "flagships" for increasing public interest and support of conservation programs around the world, but their decline often persists, because of pollution, habitat alteration, and fragmentation or direct/indirect human disturbance (Virani, Watson, 1998; Brambilla et al., 2004). Their declining numbers and economic relationships warrant additional interest, and studies of total raptor populations are needed as a means by which we may elucidate their responses to changing pressures and environmental conditions (Smith, Murphy, 1973).

In Algeria, birds have been intensively studied but the focus often was on water-related birds, passeriformes and doves. Apart from the rudimentary censuses performed by Moali and Gaci (1992) and Moali and Isenman (1990), birds of prey, however, have been carried out by a relatively few biologists who only documented the dietary and nesting characteristics of only some single species (as in Souttou et al., 2006, 2007; Telailia et al., 2013). Hence, there have been no attempts to describe spatial ecology and raptor community composition in detail comparable to those of raptor researchers around the world (see Thiollay 1977a, b, 1989, 2007; Piana, Marsden, 2012; Zilio et al., 2013).

In this article, we aim at filling these gaps of knowledge by examining the raptor assemblage patterns in northeastern Algeria, in terms of species richness, abundance, and breeding characteristics, and the main environmental drivers of assemblage patterns in order to establish a live data observatory that can help build the local expertise needed to monitor these emblematic species in the future and implement a sound strategy for their effective safeguarding.

Material and methods

Study area

Field data were collected from seven provinces (Wilaya) of northeastern Algeria (Mila, Constantine, Oum El-bouaghi, Guelma, Annaba, El-Taref, and Souk-Ahrass), historically known as Numidia (37°08′ and 35°41′ N, 5°48′ and 8°68′E) (Isenmann, Moali 2000; PASNB, 2003). It is a region with an area of about 31,000 km^2 with considerable landscapes and climates variation and where both forest and agricultural lands occupy two-thirds of the total area (Isenmann, Moali 2000; Coulthard, 2001; PASNB, 2003). Geographically, the study area can be divided into two distinct regions of topography and climate. From the Mediterranean Sea southwards, we can recognize two main ecoregions.

The coastal strip

This zone covers the northern part of Numidia; it is located in the humid and sub-humid bioclimatic zones receiving more than 1,000 mm of rainfall per year, with 3–4 months during the northern summer (July/August to October) (Isenmann, Moali 2000; Coulthard, 2001; PASNB, 2003). It is an area dotted with woodlands dominated by holm oak (*Quercus ilex*), cork oak (*Q. suber*), xen oak (*Q. canariensis*), Aleppo pine (*Pinus halepensis*), maritime pine (*P. pinaster*), atlas cedar (*Cedrus atlantica*), and Mediterranean scrub (also called as maquis/macchia or garrigue). This area can also characterized by woody vegetation including wild olive tree (*Olea europaea* var. *sylvestris*), dwarf palm (*Chamaerops humilis*), Oleander (*Nerium oleander*), and lentisk (*Pistacia lentiscus*) (Isenmann, Moali, 2000; PASNB, 2003). The valleys and low-lying plains of the region include the most fertile and productive arable agricultural land in Algeria, and most of the large centers of human population are concentrated here (Coulthard, 2001; Samraoui, Samraoui, 2008).

The inland region (hauts-plateaux)

Highlands occupy the southern part of Numidia and is located in the semi-arid zones receiving 100–200 mm of annual rainfall (Isenmann, Moali, 2000; PASNB, 2003). The Hauts Plateaux consists of a huge basin, lying at fairly high altitude between the parallel mountain ranges of the Tell Atlas to the north and the Saharan Atlas to the south (Coulthard, 2001; Samraoui, Samraoui, 2008). This area is steppes that are mostly used extensively for sheep rearing and covered with alfa grass (*Stipa tenacissima*), wormwood (*Artemisia herba-alba*), and *Lygeum spartum* (Isenmann, Moali, 2000; PASNB, 2003). On this region, there are large areas of wheat cultivation and heavy grazing by cattle, sheep, and goats on non-arable areas (Coulthard, 2001).

Data collection

Raptor abundance

An average of 10 roadside (on each road) surveys were conducted on 27 different routes for 2 consecutive breeding seasons (from March to August of 2014 and 2015) covering an area of 1,363 km in length and about 70% of the study region (Fig. 1). Each route was surveyed six times in the two breeding seasons. All surveys were conducted between 08: 00 and 16:30 at vehicle speeds of 40 km/h or less. Brief stops were made to identify and record observed birds. Only birds initially seen with the unaided eye were recorded. Binoculars (10×40 and 8×42) were used to aid in identification.

Raptor nesting and assemblages

The majority of the raptor species likely to nest on raised natural substrates (especially trees and cliffs). Also, it should be noted that none of the cavity and burrow nesting species excavate their own nests and are, therefore, dependent on the presence of existing cavities or burrows (Bird, Bildstein, 2007; ULRP, 2013). As a result, searches for cliff cavities, tree cavities, or burrows can be a useful way to identify potential nesting sites before the nesting season (Bird, Bildstein, 2007; ULRP, 2013). According to these suggestions, we collected data on raptors and their habitats for a set of cliffs where breeding activity was recorded at least once between early March and early September in the years 2014 and 2015. Along the 27 routes (roadside point transect) overall, active cliffs and assemblage sites were recorded and located with a GPS, plotted on 1:50,000 topographic maps (Arc/Map 10; ESRI, 2010). Also we have created a separate sensitivity map (MapInfo, 2010) for the most abundant raptor species.

Data analysis

We calculated the total number of individuals detected on all surveys, as well as species totals, relative abundance (%) (n/N × 100, where n is the count of a particular bird species and N is the total number of individuals counted for all species during each count session), regional occurrence (frequency of detection: we divided the number of surveys during which the species was recorded by the total number of conducted surveys), Jaccard›s coefficient of community similarity (it is a measurement of similarity for two samples, with a range from 0 to 100%, the higher the percentage is, the more similar is the two populations:

J = numbers of species shared between both regions/the total number of species shared and un-shared × 100), and Shannon diversity index ($H' = [\Sigma Pi \ln Pi]$, where H' = diversity index; Pi = is the proportion of each species in the sample) (Magurran, 1988). We classified relative abundance into four species abundance classes: very common (10–26% of all individuals detected), common (3–5%), uncommon (1–2%), and rare (<1%) (Jensen et al., 2005). We used BioDiversity Pro 2.0 software to generate a species accumulation curve to evaluate the probability that our 2-year, 27-route, roadside, survey design was adequate for documenting all detectable raptor species (Jensen et al., 2005).

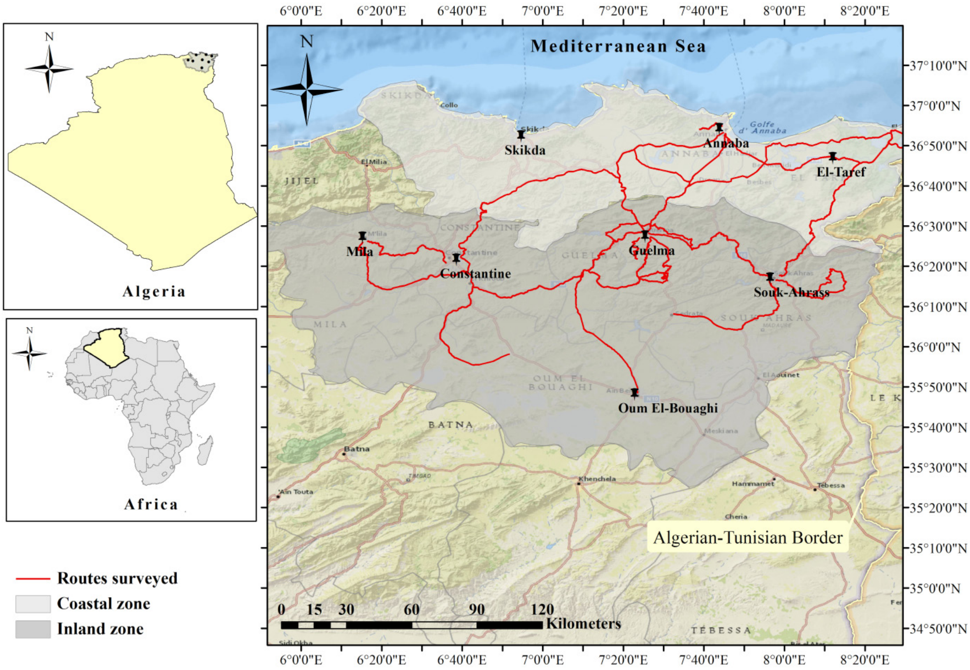

Fig. 1. Map showing the study region and the surveyed routes (MapInfo 2010 by authors).

We then calculated the mean number of individuals per species per route (mean number per route) by year and region. For this comparison, we used the 27 routes surveyed in the 2 years: inland region (17 routes) and coastal region (10 routes). For all inventoried species, we used paired t-tests to evaluate two hypothesis (1: mean number per route 2014 = or ≠ mean number per route 2015; 2: mean number per route inland region = or ≠ mean number per route coastal region). Differences were considered significant at $P < 0.05$.

Results

Diversity abundance and status of diurnal raptors

We counted 936 raptors representing 14 species under 3 families (Table 1). Accipitridae with 9 species is the richest family in species number, followed by Falconidae (4 species) and Pandionidae with only 1 species. The three most abundant species, black kite (*Milvus migrans*), common kestrel (*Falco tinnunculus*), and Egyptian vulture (*Neophron percnopterus*), comprised 70% of all individuals and are seen on 90–96% of all routes. The four rare species, Bonelli's eagle (*Aquila fasciata*), short-toed snake eagle (*Circaetus gallicus*), red-footed falcon (*Falco vespertinus*), and western osprey (*Pandion haliaetus*) have the relative abundance of ≤1% of all individuals seen and are detected on <30% of all the routes. Three additional species, the booted eagle (*Hieraaetus pennatus*), long-legged buzzard (*Buteo rufinus*), and black-winged kite (*Elanus caeruleus*), are classified as common and together comprised 15% of all individuals. The remaining species are uncommon and have the relative abundance of 1–3%. Species classified as common are detected on 56–92% of all the routes, whereas uncommon species are detected on 10–40% of the routes. In accordance with the BirdLife Checklist Version_7(2014), only the Egyptian vulture have the endangered species status, while the red-footed falcon (*Falco vespertinus*) is considered to be near threatened. The remaining species are assigned the status of "Least Concern" (Table 1).

There are at least 14 species of raptor in the region. The fact that the curve seems to level off after the 24 routes are added up might indicate that most of the species have been found (Fig. 2). Otherwise, the number of surveyed routes is adequate for documenting all species detectable by roadside point count surveys in the study area. Specifically, all 14 species are detected with 24 routes (85% of all routes surveyed).

Yearly comparisons

Among the 14 raptor species detected in this study, no significant differences are observed in the mean number per route (both p-value more than 0.05 under one-sample t-test) between the two years of study (Table 2). There are no annual changes in the actual population size of northeastern Algeria's raptors.

Regional comparisons

The greatest number of species (14) is detected in the coastal region (Fig. 3). However, species numbers were relatively similar between the regions. The diversity index was higher in the coastal zone during both the years. Species accumulation curves indicated that the number of routes surveyed during each season is adequate to detect the majority of species for both regions (Fig. 4). The raptor community (Jaccard's coefficient of community similarity) in the coastal region versus inland region differed by 14%. However, 12 species were shared in each region.

Seven of the 14 species exhibited regional differences in the mean number per route ($p < 0.05$ under one-sample t-test; Fig. 5). The red-footed falcon, short-toed snake eagle, black-winged kite, western marsh harrier, and western osprey are more numerous in the coastal region than in the inland region during the breeding seasons. In contrast, the two vultures are abundant in the inland zone.

Nest characteristics and distribution

Three varieties of raptor nest building strategies have been detected in northeastern Algeria (Table 3). Almost all raptor species prefer to nest on cliff face recesses (90% of all nests detected during

Table 1. Ecological status and relative abundance of diurnal raptorsinventoried in the northeastern region of Algeria during the breeding periods of 2014 and 2015.

Family	Scientificnames	Total	Ooccurrence frequency(%)*	Relative abundance	Status**
Accipitridae	*Milvus migrans*	337	96.43	0.36	Least concerned
	Hieraaetus pennatus	66	92.86	0.07	Least concerned
	Aquila fasciata	17	39.29	0.01	Least concerned
	Buteo rufinus	52	85.71	0.05	Least concerned
	Circus aeruginosus	19	10.71	0.02	Least concerned
	Elanus caeruleus	34	46.43	0.03	Least concerned
	Circaetus gallicus	16	32.14	0.01	Least concerned
	Gyps fulvus	22	3.5	0.02	Least concerned
	Neophron percnopterus	108	57.14	0.11	**Endangered**
Falconidae	*Falco peregrinus*	23	32.14	0.02	Least concerned
	Falco tinnunculus	209	89.29	0.22	Least concerned
	Falco biarmicus	19	25.00	0.02	Least concerned
	Falco vespertinus	12	3.57	0.01	**Nearthreatened**
Pandionidae	*Pandion haliaetus*	2	7.14	0.002	Least concerned

*Relative abundanceclass: Very common = 10-26% of all individuals detected; Common = 5-10%, Uncommon = 1-5%, Rare ≤1%. **Bird Life Checklist Version_7 (2014).

Table 2. Mean number of individuals (±SD) detected per route (mean/route) during diurnal raptor surveys in the north-east of Algeria during the tow breeding seasons (2014 and 2015).

	2014	2015	One-sample t-test
Black Kite	4.54 (±2.69)	4.04(±2.33)	t= -0.74, p = 0.46
Booted Eagle	2.50(±1.23)	2.00(±1.28)	t= 1.49, p= 0.14
Bonelli's Eagle	0.61(±0.92)	0.54(±0.79)	t=-0.31, p= 0.75
Long-legged Buzzard	1.50(±1.07)	1.29(±0.76)	t=0.86, p=0.39
Peregrine Falcon	0.61(±1.07)	0.57(±0.92)	t=-0.13, p=0.89
Common Kestrel	5.00(±2.72)	5.04(±2.59)	t=-0.05, p=0.96
Lanner Falcon	0.46(±0.92)	0.50(±0.92)	t=0.14, p=0.88
Egyptian Vulture	1.39(±1.52)	1.39(±1.45)	t=-0.03. p=0.98
Red-footed Falcon	0.39(±2.08)	0.43(±2.27)	t=0.06. p=0.95
Short-toed Snake Eagle	0.57(±0.96)	0.57(±1)	t=0.02. p=0.94
Griffon Vulture	1.1 (±0.77)	1.32(±0.72)	t=0.07. p=0.98
Black-winged Kite	1.21(±1.55)	1.21(±1.47)	t=0.04. p=0.96
Western Marsh Harrier	0.68(±2.87)	0.68(±2.72)	t=0.03. p=0.95
Western Osprey	0.07(±0.26)	0.07(±0.26)	t=0.02. p=0.096

raptor surveys). Black kite, booted eagle, long-legged buzzard, and black-winged kite have also built their nests with very low proportion (6% of all nests detected) on sturdy trees. The best trees for these sorts of nests are cork oak (*Quercus suber*), large eucalypts, and pines. Exceptionally, common kestrel exhibited an anthropogenic character because some nests have been found on

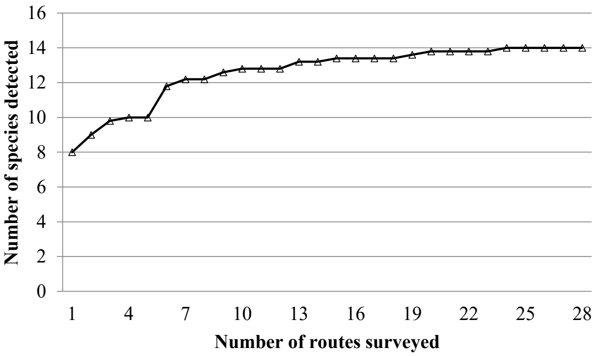

Fig. 2. Species accumulation graph of raptor species detected in 28 survey routes in the northeastern region of Algeria during the two breeding seasons.

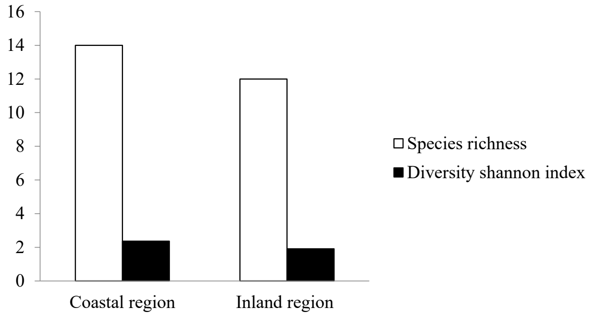

Fig. 3. Raptor species numbers and diversity in the coastal and inland regions of northeastern Algeria for combined years during the breeding seasons (2014 and 2015).

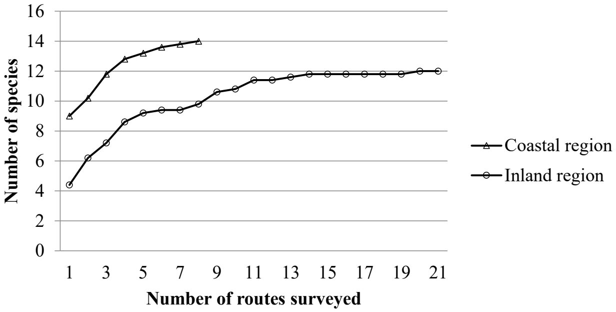

Fig. 4. Species accumulation curves for raptors detected in the coastal and inland regions of northeastern Algeria for combined years during the breeding seasons (2014 and 2015).

the ledges of high-rise buildings in or around cities. Black kite and common kestrel nests are reported most frequently than the other birds (Table 3) and in the highest numbers (82 and 57 nests, respectively) followed by the Egyptian vulture (19) and booted eagle (17). Among the 20 raptor assemblages with 186 nests detected (Fig. 6; Table 3), the greatest concentration of raptor nests occurs in the inland zone (95% of all nests detected during raptor surveys). Only one raptor assemblage is detected in the coastal region. In addition, almost all the raptor species (18 assemblages) are found nesting at a higher altitude and all most on active cliffs located at 900–1,000 m in distance from the sea (Fig. 7).

Discovering raptor species nests

We describe in this section nest characteristics and locations of the four most frequented raptor species:

Black Kite (*Milvus migrans*)
This species is widely distributed throughout the inland region from 6°10′0″ E to the Algerian–Tunisian border (Fig. 8). Nests are typically found on high cliff and rock ledges. The number of active nests within each assemblage varies from 2 to 16. Guelma province is the most important nesting area.

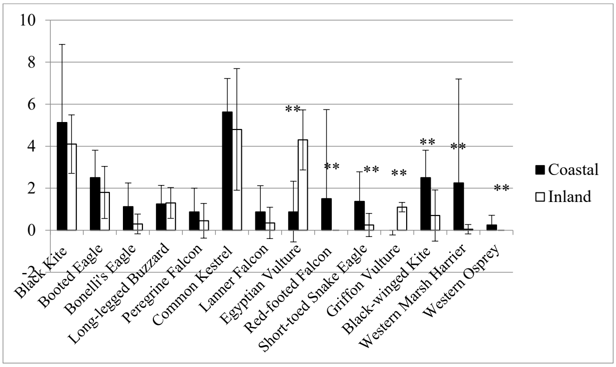

Fig. 5. Mean number of individuals (±SD) detected per route during raptor surveys in the coastal and inlands regions of northeastern Algeria during the breeding seasons (** significant differences).

Common Kestrel (*Falco tinnunculus*)
This species is also widely distributed in the inland region from 6°10′0″E to the Algerian–Tunisian border (Fig. 9). Nests are typically found on high cliff, on rock ledges, and also on high-rise buildings. Guelma and Souk-Ahrass are the two provinces most occupied by breeding kestrels.

Egyptian Vulture (*Neophron percnopterus*)
Seven vultures nesting sites have been recorded in northeastern Algeria, exclusively in the inland region (Fig. 10). The number of active nesting sites varied from 1 to 4. Souk Ahras province seems to be the most important nesting area for this endangered raptor species.

Booted Eagle (*Hieraaetus pennatus*)
All the nesting sites reported in this study were located within Guelma province (Fig. 11). All active sites are shared by little number of pairs, less than 3.

Discussion

Despite high raptor diversity and species of conservation importance, little is known about the structuring of raptor communities in North African regions. Almost all studies were focused on

Table 3. Different nest types and their location (number of nests) detected during diurnal raptor surveys in the north-east of Algeria during the tow breeding seasons (2014 and 2015).

Species	**Tree-nesting raptors**			**Cliff-nesting raptors**	**Settelment**
	Cork oak	**Eucalyptus**	**Pine**		
Black Kite	2			82	
Booted Eagle	1			10	
Bonelli‘s Eagle				2	
Long-legged Buzzard		1		4	
Peregrine Falcon				7	
Common Kestrel				57	12
Lanner Falcon				5	
Egyptian Vulture				19	
Black-winged Kite		2	1		
Total	**3**	**3**	**1**	**186**	**12**

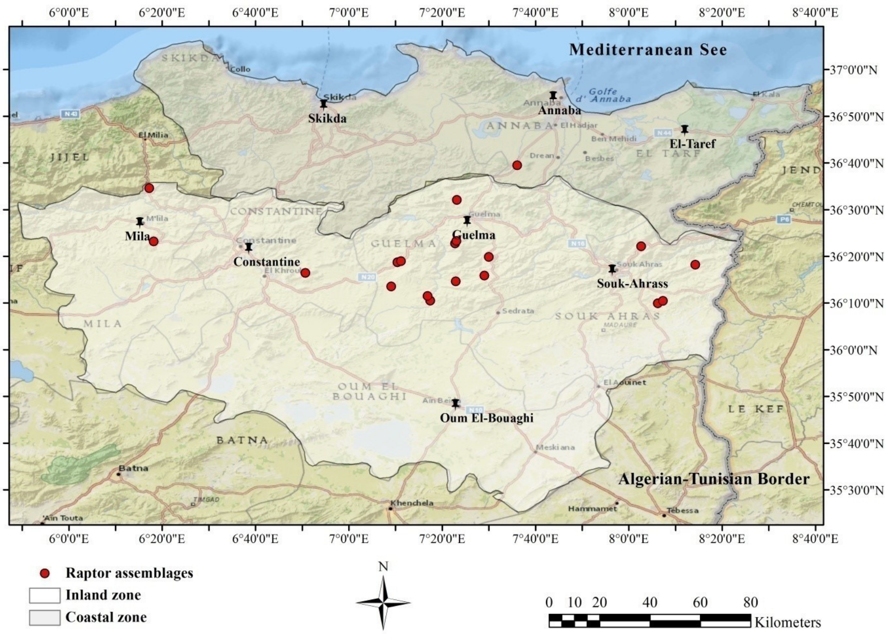

Fig. 6. Raptor breeding assemblages detected during raptor surveys in the north-east of Algeria during the two breeding seasons (2014 and 2015) (MapInfo, 2010).

tropical regions (including all countries between the Tropic of Cancer and Tropic of Capricorn; see Virani, Watson, 1998). Also, most of the available information about raptors in Algeria and the rest of North African countries is decades old. Indeed, the field study of Moali and Gaci (1992) in late 1980s remains one of the last studies about breeding raptors in the region. Since then, studies are few and far between; the accessible finding is especially about vultures status in Algeria and the other North African countries (such as in Amezian, El Khamlichi, 2015; Cherkaoui, 2005; Djardini et al., 2014) or about the dietary and nesting characteristics of some single species (as in Manaa et al., 2013; Telailia et al., 2013). Therefore, this article is the first to illustrate at a relatively broad-scale (about 31,000 km²/3,120,000 ha) the spatiotemporal (mapping) evolu-

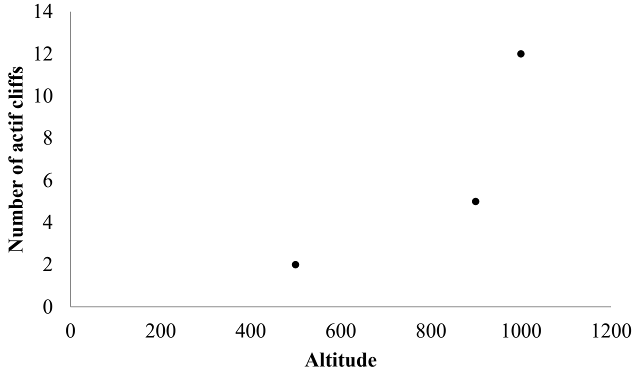

Fig. 7. Relationship between altitude and number of active cliffs.

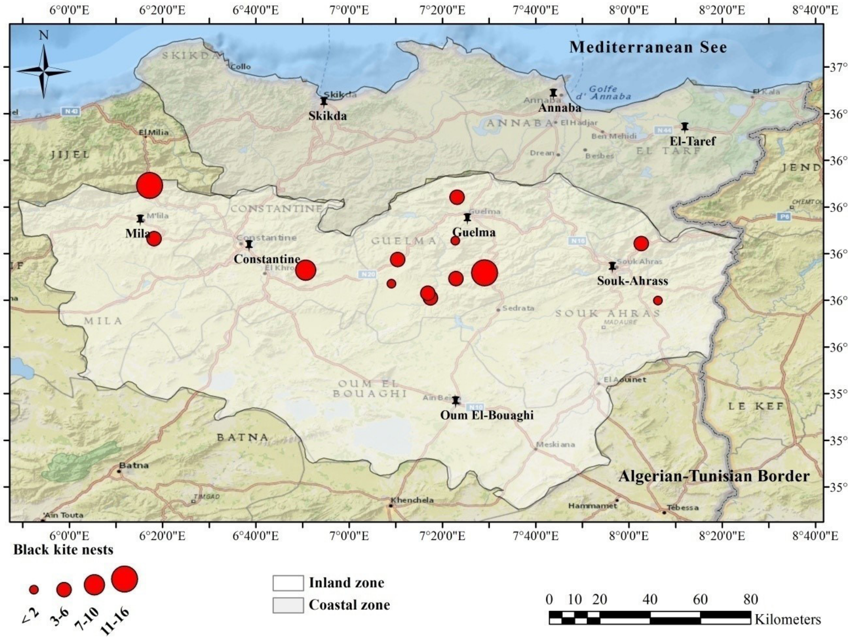

Fig. 8. Geospatially referenced map of the most important black kite nesting areas (MapInfo, 2010).

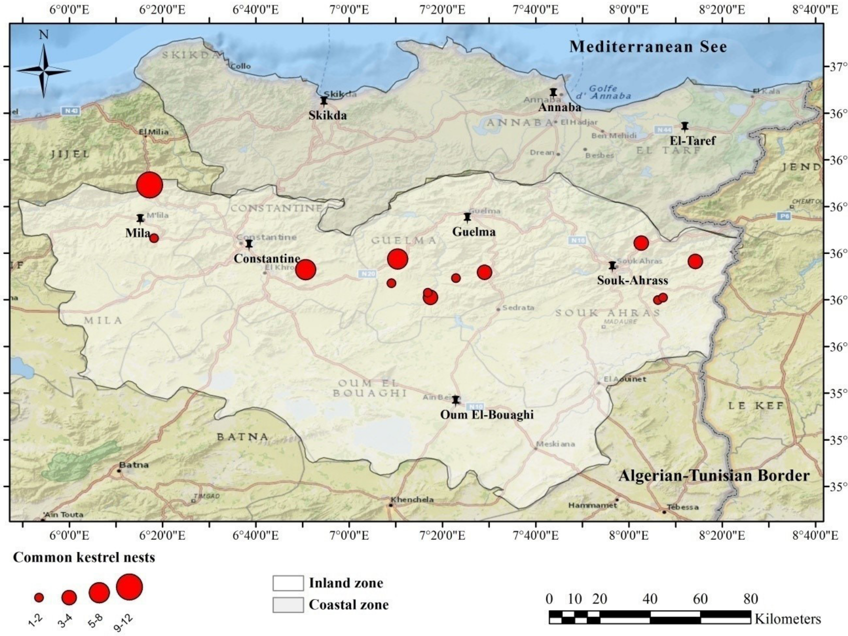

Fig. 9. Geospatially referenced map of the most important common kestrel nesting areas (MapInfo, 2010).

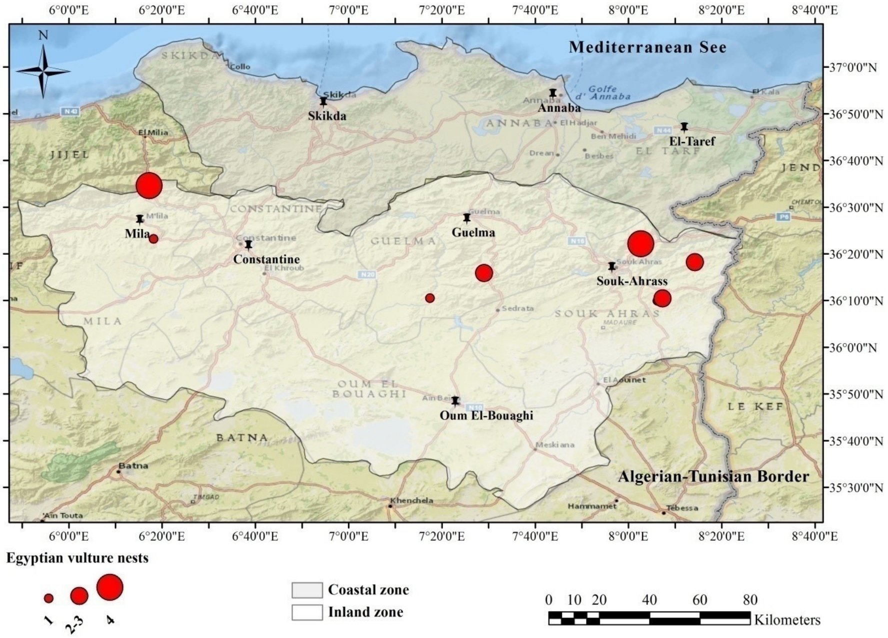

Fig. 10. Geospatially referenced map of the most important Egyptian vulture nesting areas (MapInfo, 2010).

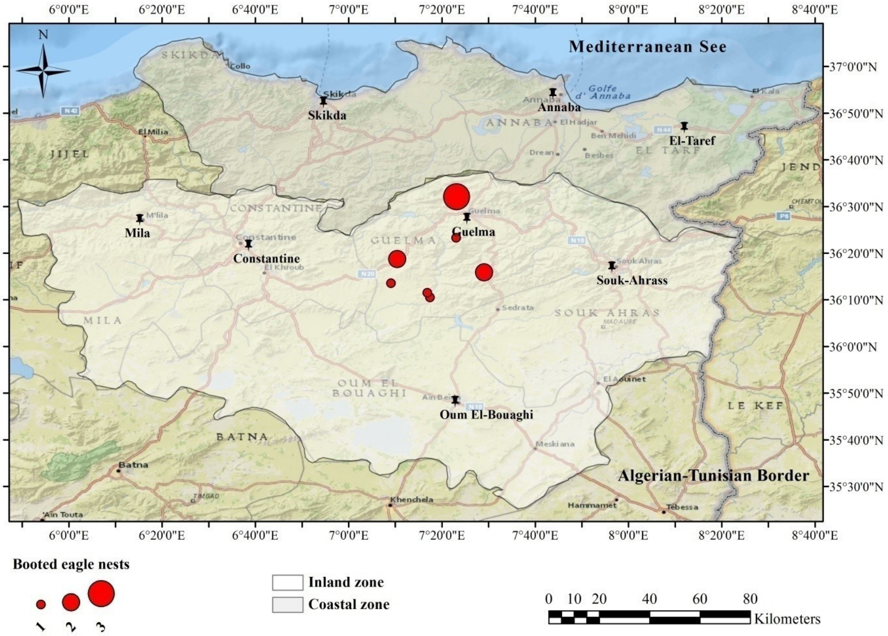

Fig. 11. Geospatially referenced map of the most important booted eagle nesting areas (MapInfo, 2010).

tion of the breeding raptor populations observed consistently in two consecutive years of study. Although the study covered a limited area (raptor individual's required large geographic areas), the surveyed avifauna was found to be diverse. It was represented by almost half (14 species) of the nesting raptor species described in Algeria (30 species listed by Moali and Isenmann, 1990). Meanwhile, the area seems to be less diversified when compared with the Kabylie region of northern Algeria (18 species identified by Moali and Gaci, 1992). Differences in species richness may be consequence of considerable landscape variations between the two regions. The occurrence of the Kabylie region within the Tell Atlas mountains (high landscapes), which is almost designated as national protected park (Djurdjura) (Moali, Gaci,1992), probably contributes to the maintain of diversified raptor populations when compared with the study region (almost extended landscapes) that is often subjected to intense agricultural and agribusiness activities (two-thirds of the total study area; Isenmann, Moali, 2000; PASNB, 2003). It is well known that the significant changes in the conditions of existence of biota species occurred under intensive human impact on the environment (Blinkova, Shupova, 2017). Intensification of agriculture and high levels of pesticide use threaten many raptor species because they result in reduced prey availability in the region (Karakas, 2015; Thiollay, 2006). The relatively high value of the region is mainly attested by the occurrence of important numbers of threatened species such as Egyptian vulture and red-footed falcon. With 19 active nests found, we can confirm that Algeria has the largest population of the breeding Egyptian vulture in the Maghreb (Morocco, Algeria, Tunisia, and Libya; in the Middle Atlas Mountains of Morocco, Amezian and El Khamlichi (2015) counted a total of 48 nesting Egyptian vultures). Despite their breeding status (Isenmann, Moali, 2000), the red-footed falcon was only observed associated with rubbish dumps (36.689064 N. 7.699592 E) in El Taref Province (coastal region) and no active nests have been found.

Raptor species show a varying level of differentiation in nest-site characteristics (Poirazidis et al., 2007), but the large-scale spatial analyses of our region illustrated further similarities. We indicated that almost all raptor species (90% of all nests detected) preferred to nest within multispecies assemblages (mixed colonies). It has been observed that juvenile and adult survival is higher for individuals born or living in high-density areas, at least in some populations (Forero et al., 2002). All these loose colonies occupied altitudinal cliffs within the inland region (semi-arid zones) rather than coastal region. Cliff height is fundamental for a species of such size and weight (Cramp, Simmons, 1980). High-elevation cliffs generate strong updrafts and produce optimum flight conditions for soaring raptors (Pennycuick, 1973). Especially for vultures, this result is consistent with some regions of continental Europe where colonies are also restricted on cliffs located at higher altitude (Xirouchakis, Mylonas, 2005). Also, the nesting richness of the inland region is probably due to their semi-arid character (Isenmann, Moali 2000; PASNB, 2003), as suggested by some results found in southeastern Spain, where a number of raptor species usually favor semi-arid landscapes with large steep cliffs (Martínez et al., 2008).

In urban environments, only the common kestrel seems to be relatively able to breed within cities and is the most synanthropic species, mainly attracted by the abundance of feeding (as rabbit availability) and nesting resources (high-rise buildings) (Donázar et al., 2016). In contrast, the remainder species are very sensitive and occupied only natural areas, very far from any human activities.

The reason for this cliffs selection across the study area may be explained by a combination of factors acting synergically: (1) the heterogeneous distribution of resources, the region is characterized by high elevations and grasslands forming mosaics with oak, alpine, and cedar forests, which are patchily distributed; (2) non-natural mortality caused by man, for example, illegal hunting, electrocution, or collision with electricity cables or pylons.

Because of their large area requirements and trophic specialization, raptors have been proposed as indicator species of habitat quality (Blendinger et al., 2004). It is thought that an area of habitat sufficient to maintain a viable population of all members of a raptor assemblage should be large enough to maintain many other species as well. The main conclusion derived from our study is that altitudinal rocky cliffs surrounded by grasslands and forests are important for the conservation of raptors. Also we have provided a first spatial localization of the most important nesting areas of diurnal raptors and first evaluation of their population size and status [not yet included in the last updated African Raptor DataBank (ARDB, 2007)]. Knowledge obtained from this study is expected to be useful for raptor researchers to monitor and build a strong future study in order to preserve the remarkable diversity of these emblematic species in northeastern Algeria and implement a sound strategy for their effective safeguarding.

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THE GEOSPATIAL UNDERSTANDING OF CLIMATE-SMART AGRICULTURE AND REDD+ IMPLEMENTATION: INDIAN PERSPECTIVE

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Abstract

Ahmad F., Farooq A., Goparaju L., Javed R.: The geospatial understanding of Climate-Smart Agriculture and REDD+ implementation: Indian perspective. Ekológia (Bratislava), Vol. 39, No. 1, p. 72–87, 2020.

Geospatial technology has an enormous capacity to analyze large and diversified datasets for evaluating the hidden spatial relationship which provides a better comprehension of the subject and helps significantly in policymaking and planning future strategies.
This study has examined the relationship among diversified remote sensing and GIS datasets such as GHG emission from cropland, rice cultivation area, agro-ecological region, Land use/Land cover (LULC) categories, long-term NDVI (1982–2006) based negative changes, agriculture vulnerability, drought-prone area and future (2021, 2050) climate change anomalies (RCP-6) of India for better understanding and knowledge of the GHG emission scenario, vegetation health, LULC, agriculture vulnerability, and future climate change impact. The LULC analysis revealed that 49.6% (1 628 959 km²) of the geographical area was found to be under category 'cropland'. The 32.5% of the total cropland areas are used for rice cultivation whereas around 76% of this rice cultivation area is producing high GHG emission (>1000 Mg CO_2 e/yr.). LULC categories 'Cropland' and 'Plantation' show the long-term (1982–2006) negative change equivalent to 19.7 and 70.2% respectively. Similarly, around 56% of LULC categories representing the forest show the long-term negative change whereas the maximum change (139 867 km²) was found in the category of 'Deciduous Broadleaf Forest'. The 30.6% of the LULC category of 'cropland' falls in very high agriculture vulnerable areas whereas 31.7% of the same category falls in the drought-prone area. The significant increase in temperature and abrupt rainfall patterns were observed during Kharif and Rabi seasons in the future. Such variation of climate parameter in the future not only adversely affect the agriculture crop production but also the natural vegetation of India.
The outcomes of the present study would support the policymakers of India to implement the climate-smart agriculture (CSA) and REDD+ on an urgent priority based on a proper evaluation of the socio-economic condition of the poor people. It will certainly help in the reduction of GHG emission, forest amelioration, will bring the resilience in livelihood and mitigate the poverty among the rural communities for the betterment of people.

Key words: GHG, LULC, NDVI based negative change, agriculture vulnerability, climate anomalies, India.

Introduction

Greenhouse gases (GHGs) such as carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) are increasing on the Earth's surface these days and significantly increasing the atmospheric temperature and rainfall pattern (IPCC, 2014). The total CO_2 equivalent emission estimates in India were about 2008.67 Tg (without land use, land-use change, and forestry (LULUCF) sector) (Energy: 69%; Agriculture: 19%; Industrial process: 9% and Waste: 3%) whereas the estimates of emissions were of the order of 1831.65 Tg CO_2 equivalent (with LULUCF sector) which significantly reflect LULUCF as a whole acts as a sink for CO_2 (Sharma et al., 2011). The study of Baur et al. (2015) showed that the change in the LULC pattern has a very significant connection to GHG emission. Various agricultural activities such as land clearing, cultivation of agriculture crops, irrigation, animal husbandry, fisheries, and aquaculture have a significant impact on the emission of GHGs and the consequent climate change (IPCC, 2007).

The agro-ecosystem plays an important role in the global share of GHG emissions (Hou et al., 2012). Agriculture alone is responsible for about 50% of the global anthropogenic gases like CH_4, and for 60% of N_2O (IPCC, 2007). Agricultural N_2O emissions are predicted to increase (23 to 60%) by the year 2030 due to increased chemical and manure nitrogen inputs (Maris et al., 2016). Furthermore, paddy lands are considered to be an important source of anthropogenic CH_4, N_2O, and CO_2 and will increase CH_4 from rice fields due to an increase in the rice sown area in the future (Cai et al., 2007).

Agriculture plays an important role in the Indian economy and supports significantly to the rural livelihood structure of the country. It provides employment to 50 % of the country's population and supports 18% of the country's GDP (Madhusudhan, 2015). Drought is further an important challenge to the sustainable agriculture and food security in India which adversely affects the small and marginal farmers. Indian farmers/cultivators are extremely vulnerable to climate change because roughly two-thirds of the cultivated land is rain-fed and fully dependent on the monsoon rainfall (http://nraa.gov.in/). Climate-smart agriculture and REDD+ were implemented in part of Kenya which manifests regulatory policy framework is supportive of climate-smart agriculture, containing policies aimed at addressing food security in addition to climate change adaptation and mitigation strategies (Dooley, Chapman, 2014). Geospatial technology has adequate capacity to analyze the raster/ vector datasets and examine the hidden spatial relationship in the GIS domain which provides a better understanding of the subject and helps significantly in policy planning and making sustainable strategies (Ahmad, Goparaju, 2019).

Why Climate-Smart Agriculture (CSA) and REDD+ implementation?

1. The GHG emissions are significant over India which needs to be reduced as per the international treaty.
2. India has endorsed the long-term target of limiting the temperature rise to under 2 °C (GoI, 2008) and has also made voluntary commitment for reducing the emission intensity of GDP in the year 2020 by 20–25% below that in the year 2005 at COP15 in Copenhagen (Shukla, Dhar, 2016).
3. To reduce the climate change impact and strengthen the food security and resilience in livelihood (Lipper et al., 2014).

4. To achieve a social, economic and environmental goal by optimizing land productivity.
5. REDD+ has tremendous potential to contribute to climate change mitigation, poverty alleviation, conserving biodiversity and step towards sustainable ecosystem services (UNFCC, 2012).

In the climate change scenario, climate-smart agriculture (CSA) will be a viable solution that has enormous potential to provide resilience to the poor marginalized farmers of India suffering from the climate-induced crop failure and will significantly help to mitigate GHG emission. Climate-smart agriculture (CSA) is an approach to transforming and reorienting agricultural development under the new realities of climate change (Lipper et al., 2014). REDD+ is a mechanism that aims to provide an economic incentive for the countries to protect, rather than cut down, their forests in order to reduce greenhouse gas emissions (Byrn et al., 2013) apart from conservation, sustainable management, and the enhancement of forest. Climate-smart agriculture (CSA) could be an integral part of India's REDD+ strategy in terms of (i) on-farm actions that indirectly reduce emissions from deforestation and forest deterioration; and (ii) policy, legal, and institutional actions at county, state, district and village levels that support investment/technology/guideline in and adoption of the climate-smart agricultural practices in food security, poverty mitigation, reviving the diminishing livelihood, increasing the tangible and nontangible service benefits in the rural area, optimizing the soil fertility, magnifying the farm household resilience, ameliorate the existing eco-system, protecting the existing biodiversity, and reducing the future climate change impact.

Widespread changes in rainfall and temperature patterns as well as frequent drought and floods threaten agricultural production and increase the vulnerability of people dependent on agriculture for their livelihoods. Agriculture crop production will be challenged to continue the increasing global crop production to meet the nutritional requirements of an increasing population and help achieve food security to the existing hungry people, while at the same time limiting cropland expansion and containing damages to the natural resources and other ecosystems (Falkenmark et al., 2009). Climate change (2007) assessment report reveals that the majority of hungry people living today face absolute poverty and are agriculture dependent suffer from the negative impact of agricultural production and by chronic water shortages due to ongoing and future climate changes. The agricultural production statistics show that the rates of food grain production have recently declined in several countries in spite of international efforts to optimize the global food security (Funk, Brown, 2009).

Climate plays a major factor and controls the distributions and growth of plant species and vegetation (Sykes, 2009). Kharif and Rabi are the two cropping pattern season which is adopted in many Asian monsoon countries including India. The cropping season of Kharif starts from June-October during the south-west monsoon and the Rabi cropping season is from October-March (winter). In India, rainfall, temperature, and its spatial distribution pattern is an influential factor which affects the growth of agriculture productivity, economy, and livelihood (Bothale, Katpatal, 2014). Vegetation in any area at a significant scale has been playing a vital role in balancing the stability of sustainable habitat and has a relationship with the existing ecosystem and climate (Bing et al., 2014).

The objectives of the present study are to create maps in GIS environment, examine the spatial distribution patterns and relationship/query of diversified datasets such as GHG emission, rice-producing area, agro-ecological regions, land use/ land cover (LULC), NDVI based negative change, agriculture vulnerability, drought-prone area and future (2021, 2050) annual, Kharif and Rabi season climate change anomalies (RCP-6) over India.

Material and method

Study area

The study area includes the entire terrestrial land of India with geo coordinate 6°44'N to 35°30'N latitude and 68°07'E to 97°25'E longitude. The vegetation of India varies significantly in all diversified ecological and geographical regions based upon climatic conditions, edaphic and topographical variation which is reflected in the form of its structural complexity, species diversity, productive and protective characteristics. Over 60 percent of India's total land is under agriculture and nearly 23 percent covered by forests (http://www.fao.org/india/fao-in-india/india-at-a-glance/en/). Kharif crops are cultivated during the monsoon season. The rice cultivations in the waterlogged area are the important source of GHG emission whereas it magnifies due to the use of inorganic fertilizer widely practiced to enhance the agriculture output. India is a geographically diverse country surrounded by Himalaya's ranges, Thar desert, Gangetic delta, and Deccan Plateau in North, West, East, and South respectively and home of various ecosystems which retain vast agro-ecological diversity.

Data acquisition and processing

In the present study, we have used the various dataset from a diversified source are given in Table 1.

We have used the circa 2000 estimates of Greenhouse gas (GHG) emissions (due to rice cultivation, peatland drainage, and N-fertilizer application) (Carlson et al., 2017) for better comprehension of GHG scenario in India. The map was brought into the GIS environment by digitizing all categories over India and assigned respective values (Fig. 1) for understanding the spatial pattern and their distribution. The data utilized for GHG emissions by coupling biophysical models with 5-arc-minute resolution data on land surface attributes and crop harvest and management (Carlson et al., 2017). The CH_4 emissions from paddy (flooded) rice cultivation, CO_2, N_2O and CH_4 flow from agricultural peatland draining, and direct and indirect N_2O emissions from synthetic N fertilizer and manure application. This flow accounts for the majority of GHG emissions from cropland agriculture (http://faostat3.fao.org) but excludes certain emissions sources (for example, energy for fertilizer manufacture, liming). The approach significantly reflects a crop-specific subnational assessment of how agricultural management practices interact with biophysical characteristics to generate diverse patterns of GHG emissions (Carlson et al., 2016). The rice cultivation areas of India (http://maps.unomaha.edu/Peterson/geog1000/MapLinks/India.htm) were digitized and brought into the GIS domain for further analysis.

The agro-ecological region map of India (Bandyopadhyay et al., 2009) which was cited by Ahmad et al. (2018) and all categories were brought under the GIS domain. The high Greenhouse gas (GHG) emission (>1000) category was overlaid over the agro-ecological region map and was given in figure for further analysis (Fig. 2).

We have utilized the Land use and land cover (LULC) data for the year 2005 (https://daac.ornl.gov/VEGETATION/guides/Decadal_LULC_India.html) having a 100-meter resolution for India (Roy et al., 2015). Most of the LULC class categories exhibit accuracies more than 90% whereas overall mapping accuracy and Kappa accuracy were 94.46% and 0.9445

Table 1. Various datasets and the sources used in this study.

Data used	**Source/References**
GHG emission from cropland	Carlson et al., 2017
Rice cultivation area	http://maps.unomaha.edu/Peterson/geog1000/MapLinks/India.htm
Agro-ecological region map of India	Bandyopadhyay et al., 2009 (Cited by Ahmad et al., 2018)
Long term NDVI (1982–2006) based negative changes	Geospatial world, 2012
Land use/ Land cover (LULC)	Roy et al., 2015
Agriculture vulnerability	Rao et al., 2013
Drought prone area	https://www.mapsofindia.com/maps/india/natural-hazard.htm
Future (2021, 2050) climate change anomalies (RCP-6)	NCAR GIS Program, 2012

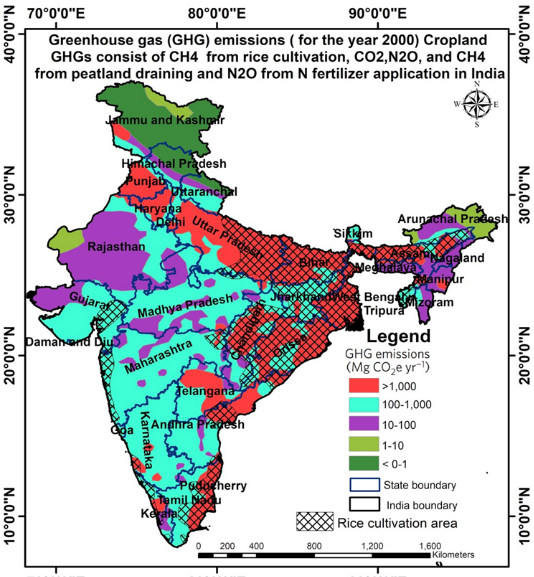

Fig. 1. Greenhouse gas (GHG) emissions (due to rice cultivation, peatland drainage and N-fertilizer application) for the year 2000 in India (Carlson et al., 2017).

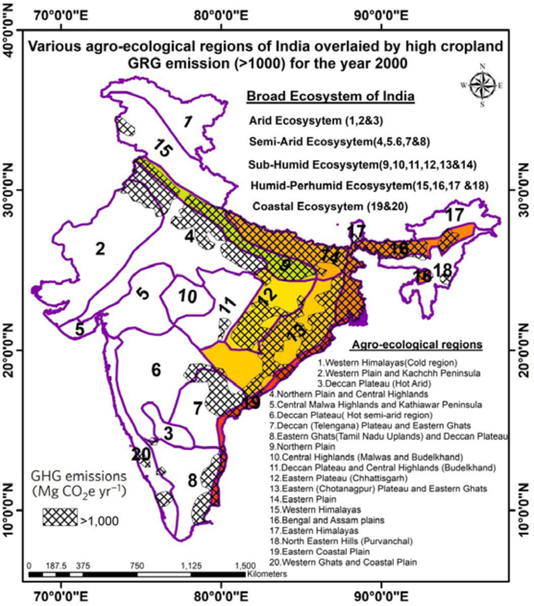

Fig. 2. Agro-ecological regions of India vs. high cropland GHG emission (>1000).

respectively for the year 2005 LULC map (Roy et al., 2015).

The NDVI value indicates that vegetation growth and vigor significantly reflects the health of vegetation. Long-term (1982–2006) NDVI map (Geospatial world, 2012) based on NOAA-AVHRR data with the spatial resolution of 8km was utilized in this study, the trend of negative change was brought into the GIS domain. In this study NDVI variations, only Max NDVI value was used (Holben, 1986) and zonal statistics were calculated using Spatial Analyst Tool in ArcGIS (ver.10.0) to determine variations in NDVI which manifest the long-term (1982-2006) change (Geospatial world, 2012). The Land use/Land cover (LULC) categories map (2005) overlaid by long-term NDVI based negative change areas over India are given in Fig. 3.

The agriculture vulnerability of India (Rao et al., 2013) to climate change (2021–2050) map was brought into the GIS environment (Fig. 4).

The drought-prone area was digitized from the Natural Hazard map of India (https://www.mapsofindia.com/maps/india/natural-hazard.htm) and overlaid over very high agriculture vulnerability map for better understanding (Fig. 5).

We have downloaded the point grid monthly temperature and precipitation anomalies (climate change scenario) data for the year 2021 and 2050 analyzed with the base period 1986–2005 over India using the RCP-6 scenario model (NCAR GIS Program, 2012). In the first step, the month-wise temperature and rainfall surface were produced from the point vector file using the kriging interpolation technique. Kriging is an advanced geostatistical procedure was performed in ArcMap using the spherical semivariogram model that generates the surface from a scattered set of z-points values based on interpolation executed by a Gaussian process. The Kharif season temperature and precipitation anomalies were produced by integrating June to October month-wise respective data because the sowing season starts in the month of June-July and harvesting season ends in the month of September to October (https://keydifferences.com/difference-between-kharif-and-rabi-crops.html). Similarly, the Rabi season temperature and precipitation anomalies were produced by integrating October to March month-wise respective data. The anomalies of Kharif, Rabi and annual temperature and precipitation prediction for the year 2021 and 2050 are given from Fig. 6 to Fig. 17 for further analysis.

Result and discussion

The analysis of Greenhouse gas (GHG) emissions

The evaluation of Greenhouse gas (GHG) emissions (Mg CO_2 e/yr.) especially from cropland for the year 2000 over India shows that 27% of the total geographical area of India is producing GHG greater than 1000, followed by 44% of area 100–1000, 19 % of area 10–100 and rest 10% are less than 10. A similar observation of GHG emissions has been reported from agriculture (INCCA, 2010). Most of the highest Greenhouse gas (GHG) emissions (>1000) states are Punjab, Haryana, Uttar Pradesh, Bihar, West Bengal, Assam Orissa, Chhattisgarh, Telangana, Andhra Pradesh and Tamil Nadu (Fig. 1).

The analysis of agro-ecological regions

The analysis of available data from various agro-ecological region of India with Greenhouse gas (GHG) emissions scenario of the year 2000 reflects the categories "Northern plain", "Eastern plain", "Eastern Plateau (Chhattisgarh)", "Eastern (Chotanagpur) Plateau and Eastern Ghats" and "Bengal and Assam plains" (Fig. 2) are showing high GHG emission (>1000 Mg CO_2 e/yr.). These agro-ecological regions of India are responsible for approximately 73% of high GHG emission

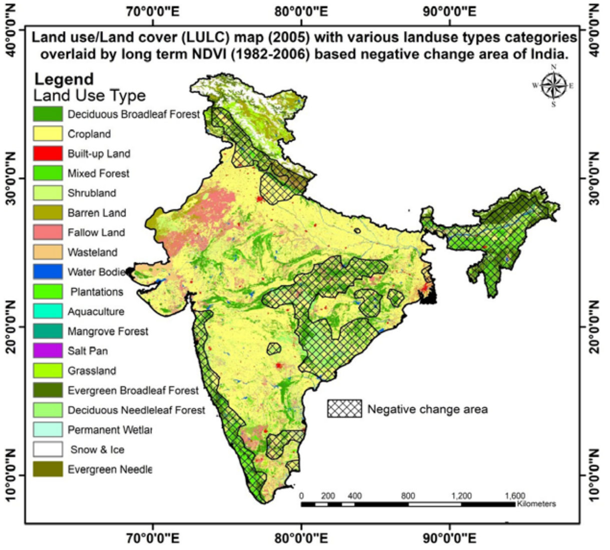

Fig. 3. Land use/Land cover (LULC) categories map (2005) overlaid by long term NDVI based negative change area of India.

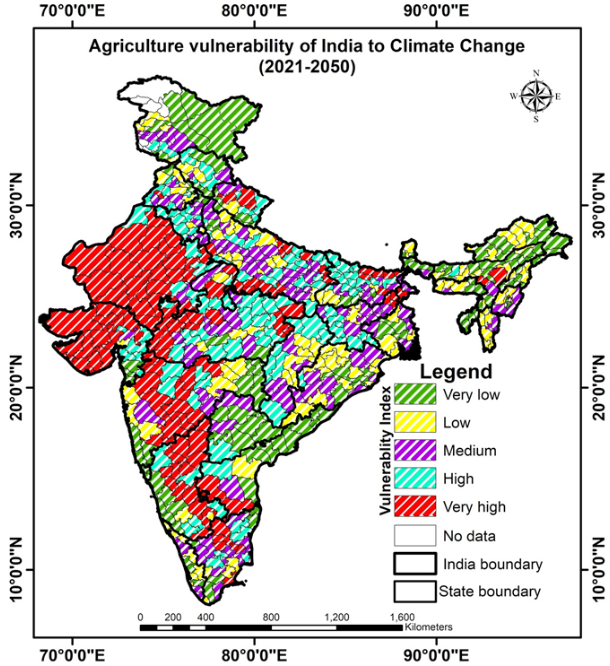

Fig. 4. Agriculture vulnerability of India (Rao et al., 2013).

(>1000 Mg CO_2 e/yr.) from cropland. The GHG emission from methane (Metric ton) reported in India in the rice field varies significantly from 3.3 to 37.5 as per the report of various scientists (Pathak et al., 2014). Hou et al. (2012) also found similar observation where they found various agro-ecosystems plays a significant role in the GHG emission.

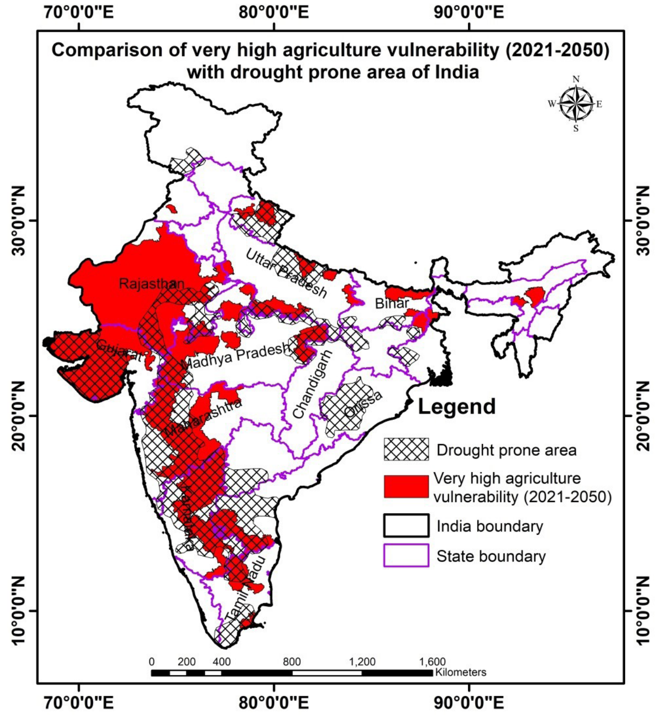

Fig. 5. Very high agriculture vulnerability vs. drought-prone area of India.

The analysis of LULC categories

The analysis of LULC categories of India revealed that around 49.6% (1 628 959 km²) of the geographical area was found to be under category 'cropland' and 2.4% (79 238 km²) area as 'plantation' category. The cross-evaluation of LULC categories with the rice cultivation area revealed that 32.5% of the LULC category of 'cropland' is used for the rice cultivation area. Furthermore, around 76% of this rice cultivation area is producing high GHG emission (>1000 Mg CO_2 e/yr.) is a matter of serious concern. The agriculture sector such as the LULC categories 'Cropland' and 'Plantation' shows the negative change equivalent to 19.7 and 70.2% respectively when it was compared with the total area of the respective category (Table 2). Land use and land cover map categories representing the forest were merged (except plantation and scrubland). The total forest area for the year 2005 in India was found to be 22% of the total geographical area. These forest areas were evaluated with long-term NDVI based analysis (Table 2). Around 56% of these forest shows the trend of negative change. This means that these forest categories have deteriorated a lot in the long run. Significant negative changes (in term of forest area) were found to be maximum over the category of 'Deciduous Broadleaf Forest' (139 867 km²) followed by 'Evergreen Broadleaf Forest' (116 926 km²), 'Mixed Forest' (89 321 km²), 'Deciduous Needleleaf Forest' (45 196 km²) and 'Mangrove Forest' (659 km²). Furthermore, the Western Ghats of the state of Kerala and Karnataka, all North-Eastern states, Orissa, Telangana, Jharkhand, Maharashtra, Chhattisgarh, Uttrakhand, and Himachal Pradesh state's forest showed that the negative change between the period 1982 to 2006 which is a serious issue. A similar observation was found where 46 lakh hectares of forests in India lost

T a b l e 2. The area statistics of various categories of LULC of India with NDVI based negative change.

Land use and land cover map of India for 2005	*Square Kilometer		
	Total area *	Total negative change area*	Negative change (%)
1- Deciduous Broadleaf Forest	315 362	139 867	44.4
2- Cropland	1 628 959	321 706	19.7
3- Built-up Land	47 255	13 723	29.0
4- Mixed Forest	152 198	89 321	58.7
5- Shrubland	187 358	49 407	26.4
6- Barren Land	101 737	2127	2.1
7- Fallow Land	224 083	21 928	9.8
8- Wasteland	41 611	2263	5.4
9- Water Bodies	101 080	32 175	31.8
10- Plantations	79 238	55 660	70.2
11- Aquaculture	215	53	24.5
12- Mangrove Forest	894	659	73.7
13- Salt Pan	80	80	100.0
14- Grassland	55 247	10 442	18.9
15- Evergreen Broadleaf Forest	179 225	116 926	65.2
16- Deciduous Needleleaf Forest	57 575	45 196	78.5
17- Permanent Wetlands	3791	635	16.8
18- Snow & Ice	91 617	880	1.0
19- Evergreen Needleleaf Forest	19 738	15 802	80.1

greenness between the period 2001 to 2014 (Nilesh, 2018). Such analysis gives emphasis on implementing REDD+ as early as possible. Similar findings of negative change were reported by Chakraborty et al. (2018) utilizing the long-term MODIS NDVI data. The negative change in vegetation not only leads to degradation in the natural forest but also into the agriculture and plantation sector adversely impact food security, livelihood resilience, regional biodiversity, and the climate.

The analysis of agriculture vulnerability

The prediction of agriculture vulnerability of India (2021–2050) shows that 26.5, 18.3, 16.6, 13.9 and 23.4% of the geographical area of India will be very high, high, medium, low and very low vulnerable to agriculture respectively. The significant very high agriculture vulnerability will be more pronounced on the western side of India. The Rajasthan, Gujarat, Maharashtra and Karnataka, part of Tamil Nadu and Andhra Pradesh states will be the highest sufferer in the future. Furthermore, these areas fall on arid and semi-arid agro-ecosystem region characterized by severe weather conditions such as low rainfall pattern, high solar radiation, high wind velocity, and increased evapotranspiration whereas productivity potential of the land is also usually low due to immature, structure-less, and very coarse texture of soil with low water retention capacity and poor nutrient status (Ahmad et al., 2018). The drought-

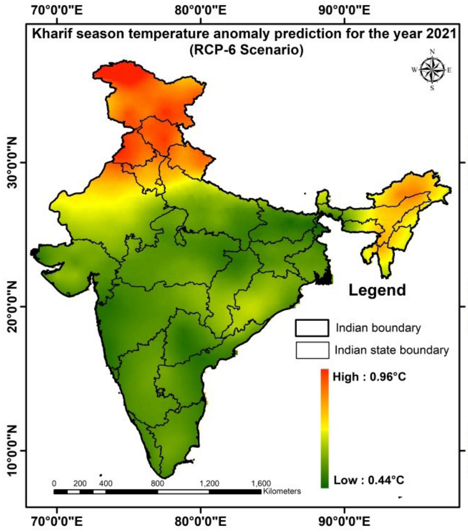

Fig. 6. Kharif season temperature anomaly (2021).

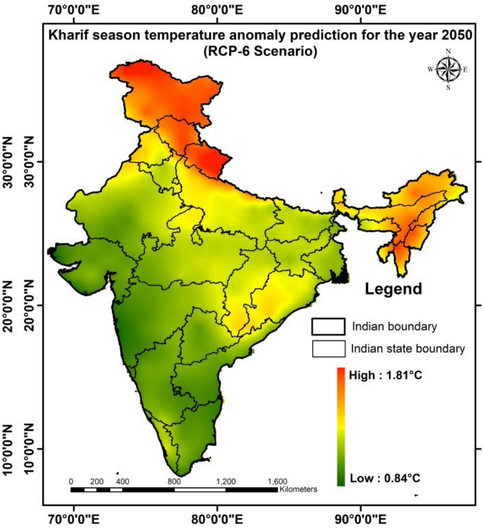

Fig. 7. Kharif season temperature anomaly (2050).

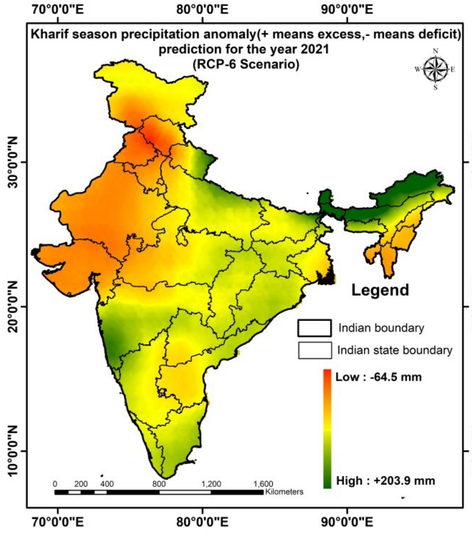

Fig. 8. Kharif season precipitation anomaly (2021).

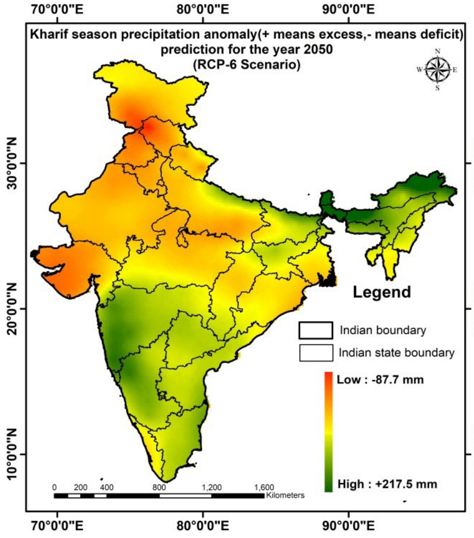

Fig. 9. Kharif season precipitation anomaly (2050).

prone area analysis shows that 38% of the geographical area of India is drought-prone. The spatial pattern is more scattered over India whereas it is more pronounced over the western and southern regions of India characterized over the arid and semi-arid agro-ecosystem region (Fig. 2). The cross-comparison of the drought-prone area with agriculture vulnerability

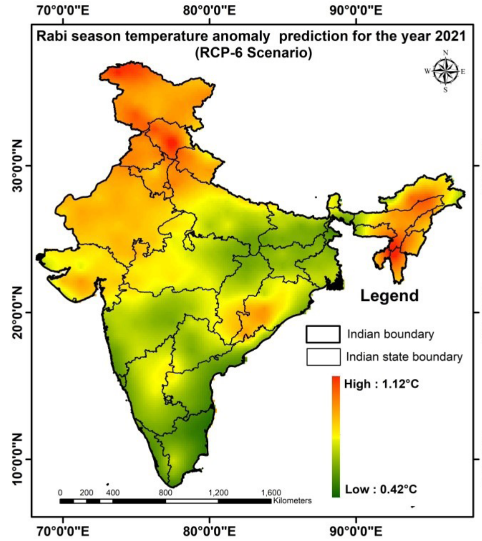

Fig. 10. Rabi season temperature anomaly (2021).

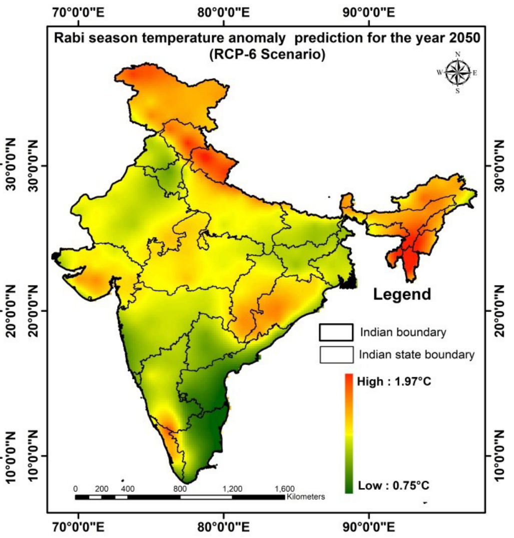

Fig. 11. Rabi season temperature anomaly (2050).

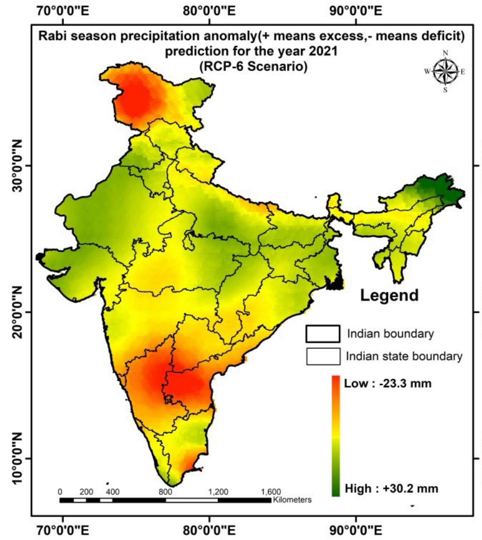

Fig. 12. Rabi season precipitation anomaly (2021).

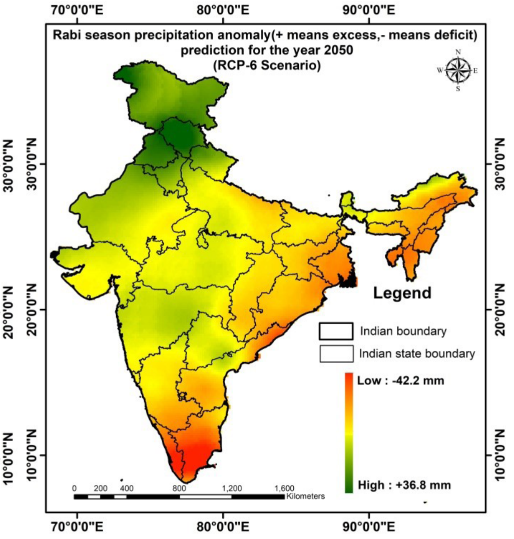

Fig. 13. Rabi season precipitation anomaly (2050).

map shows 51% drought-prone area falls on very high agriculture vulnerable area. A similar vulnerability assessment to drought was reported by Zarafshani et al., 2016.

We have also cross-tabulated the LULC category of 'cropland' with the drought-prone area and agriculture venerability. The analysis shows that 30.6% of the LULC category of

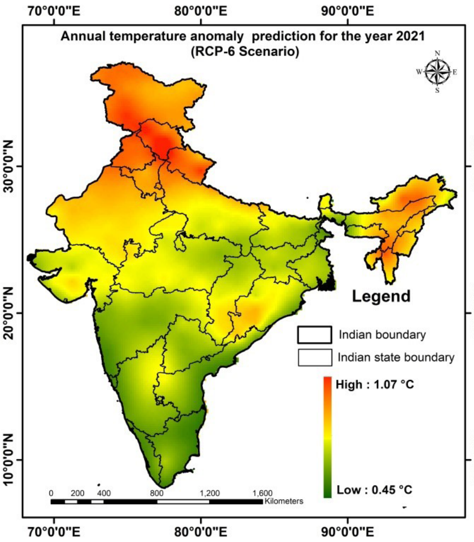

Fig. 14. Annual temperature anomaly (2021).

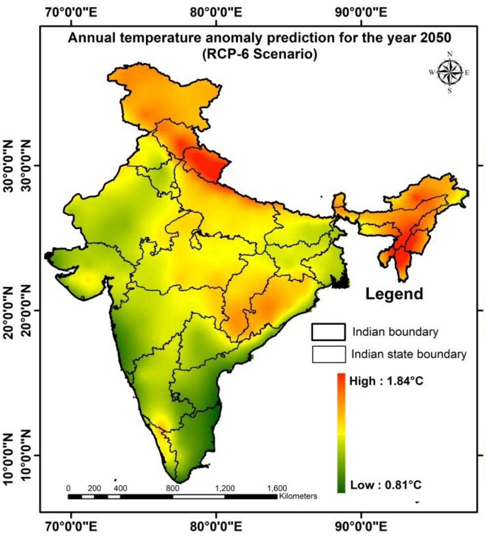

Fig. 15. Annual temperature anomaly (2050).

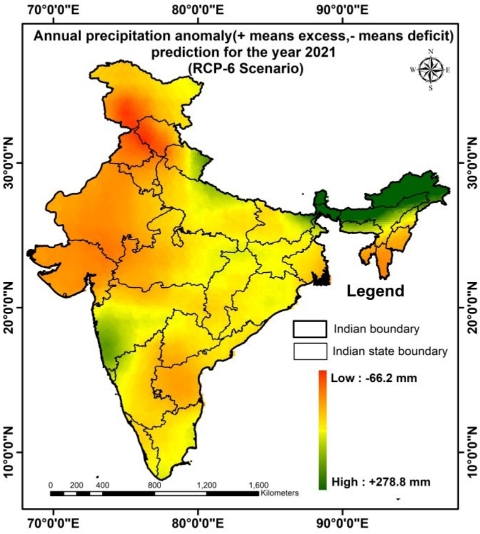

Fig. 16. Annual precipitation anomaly (2021).

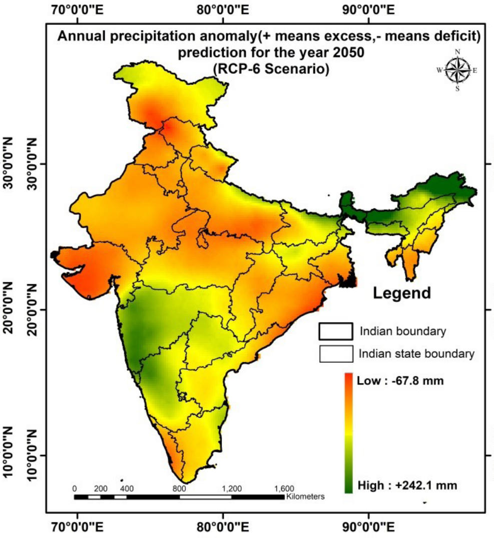

Fig. 17. Annual precipitation anomaly (2050).

'cropland' falls on very high agriculture vulnerable area whereas 31.7% of the same category falls on the drought-prone area. The analysis further revealed that 17.2% of the LULC category of 'cropland' falls on both high agriculture vulnerable areas and drought-prone areas will face tremendous pressure in the future as far as agricultural production is a concern.

The analysis of predicted Kharif, Rabi seasons climate

The analysis of predicted Kharif, Rabi and annual climate data such as temperature and precipitation anomalies for the year 2021 and 2050 shows some interesting trends over India. During Kharif season the temperature is showing an increasing trend over India with the range of (0.44 to 0.98 °C), (0.84 to 1.81 °C) for the year 2021 and 2050 respectively will significantly impact and will reduce the yield of Kharif crop such as rice, maize, soybean etc. In each degree-Celsius increase in mean temperature would, on average will decrease the yields of rice by 3.2%, maize by 7.4%, and soybean by 3.1% (Zhao et al., 2017). Furthermore, high-temperature increase during the Kharif season in the year 2021 is significant over the state of Jammu and Kashmir, Himachal Pradesh, Uttarakhand, Punjab and Haryana and Northern part of Rajasthan and most of the North East states of India. In the year 2050 temperature will be significantly high with greater intensity over the same state of India where the temperature was observed increasing for the year 2021 whereas, it further intensified in the new area of the state Chhattisgarh, Orissa and North Western Uttar Pradesh. The precipitation spatial pattern and variation during Kharif season (2021) with deficit in precipitation was observed over Himachal Pradesh, Punjab, Haryana, Rajasthan, Gujarat, western Madhya Pradesh and Southern part of North-East states of India whereas further precipitation deficit was observed (2050) in the southern part of Uttar Pradesh and northern part of Madhya Pradesh.

During Rabi season the temperature is showing an increasing trend over India with the range of (0.42 to 1.12 °C), (0.75 to 1.97 °C) for the year 2021 and 2050 respectively. Furthermore, high-temperature increase during the rabi season in the year 2021 is significant over the state of Jammu and Kashmir, Himachal Pradesh, Uttarakhand, Punjab, Haryana Rajasthan, Gujarat, part of Orissa, part of Chhattisgarh and most of the North East states of India. In the year 2050 temperature will significantly increase in the new area of Western Ghat of India with the coastal state of Kerala and Karnataka. The precipitation deficit in the year 2021 was noticeable in the state of Karnataka, Andhra Pradesh and western part of Jammu Kashmir. In the year 2050, the precipitation deficit will be in the eastern coastal states and North-East states of India whereas it will be more critical for the state of Tamil Nadu and Kerala. The study of Zhao et al. 2017 shows that Rabi season crops such as wheat yield will reduce by 6% by an increase in each degree temperature. We can finally conclude that the temperature increase and precipitation variation during Kharif and Rabi season in the future will significantly reduce the Kharif and Rabi crops such as rice, wheat, barley, and mustard production and will challenge the future food security and livelihood resilience.

The annual temperature is showing an increasing trend over India with the range of (0.45 to 1.07 °C), (0.81 to 1.84 °C) for the year 2021 and 2050 respectively whereas precipitation variation is also being observed during the same base years. The annual temperature increases in the year 2021 are notable over the northern states (Jammu and Kashmir, Himachal Pradesh, Uttarakhand, Punjab, Haryana, and Rajasthan), the northern region of Uttar Pradesh, the southern part of Orissa and North-East states in India. In the year 2050, it was further intensified in the same area except for Rajasthan. The precipitation deficit in the year 2021 was found in the northwestern region of India whereas it is more pronounced in the state of Jammu and Kashmir, Himachal Pradesh and Haryana. Similarly, in the year 2050 precipitation deficit is more scattered over India whereas it is more crucial for the state of Gujarat, Kerala, the southern region of Uttar Pradesh, the southwestern region of Jammu and Kashmir, the north region of Madhya Pradesh, coastal region of Orissa and West Bengal.

Climate change impacts and the need for Climate-Smart Agriculture (CSA) and REDD+

Increasing concentrations of greenhouse gases (GHGs) in the atmosphere are significantly maneuvering climate change. A study conducted by NASA reveals that the global temperature has been increased by approximately

1 °C in the year 2016 whereas it shows the significantly increasing trend (https://climate.nasa.gov/vital-signs/global-temperature/). A study conducted by Lal et al., 1995 predicted the increase in temperature for the year 2040 with an increase of 0.7–1.0 °C annual mean maximum and minimum surface air temperatures. The study on climate change by Ray, De (2003) revealed that there will be an occurrence of extreme events in the future. Climate change directly impacts lives of farmers/poor people in India by causing lower crop yields especially for rice and wheat (Anand, Khetarpal, 2015), threatening the food security and livelihood, whereas it has the potential to create a wide range of economic impacts (Gupta et al., 2012). Some impacts will gradually affect economic processes, such as the effect of increasing temperature on energy demand whereas others may come as extreme events, such as sudden floods, forest fires and their future events with greater intensity. India's forests are degrading at an alarming pace whereas they are significantly losing their greenness in the long run (Chakraborty et al., 2018). The deforestation and forest degradation (REDD+) will be a very effective mechanism for mitigating climate change impact by providing financial incentives for reducing deforestation and forest degradation to the rural and forest-dependent communities from international financial sources (Ravindranath et al., 2012). There is a need to find out the approach/mechanism to accelerate a process from country level, state level, district level to the village level. This will greatly enhance the livelihood of the rural tribal/poor people and significantly mitigate the poverty among them. Furthermore, India has adopted agroforestry policy in the year 2014 which will significantly support the objective of climate-smart agriculture (https://csa.guide/csa/national-agroforestry-policy-of-india) keeping the strategies to expand the use of agroforestry practices outside the natural forest's boundary (NAP, 2014). Such practices on our land-use system will also satisfy the demand for food, fuel, and fodder to increasing population in a sustainable manner for the survival and prosperity of humanity.

Based on our study we can conclude that the existing land, agriculture, forest, and agroforestry policies should be significantly maneuvered towards CSA and REDD+ to reduce GHG emissions, to protect our forest from further degradation and for the betterment of the socio-economic condition of poor people.

Conclusion

In this study, we have created various diversified thematic layers in GIS domain and significantly evaluated the spatial pattern and relationship which revealed some interesting trend to make adequate understanding of GHG emission, LULC pattern, vegetation (agriculture and forest) health and future Kharif, Rabi crop season and annual climate changes over India. Such diversified analysis, investigation of relationship and a crucial trend of these parameters at the country level of India was never executed in a GIS environment so rigorously in the past.

The total cropland in India is equivalent to 49.6% of the total geographical area. Around 32.5% of the total cropland area is used for rice cultivation whereas around 76% of this rice cultivation is producing high GHG emission (>1000 Mg CO 2 e/yr.) is a matter of serious concern. Agro-Ecological regions are important because it reflects the cropping pattern thus gives a significant correlation with GHG emission (Hou et al., 2012). Agriculture plays an important role in the Indian economy and has diversified socio-economic linkage. It is a major source of income and livelihood for rural India. The climate change significantly maneuvered the weather parameter in terms of its severity which leads to drought, irregular rainfall patterns, floods, and forest fires. These weather severities will adversely affect our agriculture and forest will be reflected in terms of productivity and will be a great challenge as far as food security is concern.

The total forest area for the year 2005 in India was found to be 22% of the total geographical area. Around 56% of these forests showed the long-term (1982–2006) negative change trend. Based on various research studies (Chaturvedi et al., 2011; Ravindranath et al., 2012; Chakraborty et al., 2018) it was found the forest of India is deteriorating in term of its greenness, tree density, and quantities and will continue to sink in future. Our study further revealed that the long-term (1982–2006) negative change was found highest (in terms of an area) in the LULC category of 'Deciduous Broadleaf Forest'. Deciduous Broadleaf Forest occupies 43.5% of the total forest cover of India and significantly harbors the large ethnic tribal community. Apart from several tangible and intangible benefits from the forest, they are the major source of livelihood, income and nourishment for them are severely threatened nowadays and leading to acute poverty. Furthermore, a situation will be more critical in the future due to climate change impact. The study of predicted climate change anomalies shows the significant increase in temperature and variation in rainfall patterns during Kharif and Rabi season will significantly impact the agriculture crop production in the future. So finally we can conclude the climate-smart agriculture (CSA) and REDD+ is the only viable solution will reduce the greenhouse emission, improve the agriculture output, check the deterioration of forest, increase the forest area, and will bring the livelihood resilience by generating the income and mitigate the poverty significantly.

Geospatial technology is one among the finest discipline whereas GIS evaluation in it is the finest approaches to examine large and diversified data sets to analyze the spatial relationship which are highly useful in drawing logical conclusion and significantly support in policy decision making process.

Limitation and future research scope

The study used a diversified dataset, therefore, the results are showing the circa estimates and can be used with precaution. There is a need for more rigorous studies similar to our study using more diversified data sets including the future climate scenarios and socioeconomic conditions of farmers/poor people/ethnic tribes will significantly reflect more meaningful results.

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MODELLING IN THE CONTEXT OF AN ENVIRONMENTAL MOBILISATION: A GRAPH-BASED APPROACH FOR ASSESSING THE LANDSCAPE ECOLOGICAL IMPACTS OF A HIGHWAY PROJECT

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Abstract

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The construction of highways leads to several environmental and landscape impacts, including the fragmentation of natural habitats for many animal species. Highway projects are therefore generally accompanied by mobilisations from the inhabitants of the areas concerned and environmental associations. This work aims to model the potential impacts of a highway project in France on ecological networks and to study the reception of the results by the opponents of this project. We have adopted a three-step approach. First, a land-cover map of the study area was produced at a fine scale of 10 m resolution. Second, we developed a multi-species approach by defining fifteen species groups representative of different habitats of our study area. Third, the design of landscape graphs and the resulting calculation of connectivity metrics allowed mapping the impact of the highway on multi-species ecological connectivity. Reflexive feedback from comments on these results by the public during a mobilisation day against the highway project allows assessment of the relevance of such a modelling approach in this context.

Key words: cartographic mediation, environmental impact assessment, environmental mobilisation, highway project, landscape graphs, landscape connectivity.

Introduction

The increase in the world population in recent decades has led to an increasing artificialisation of natural and agricultural areas to support the housing and travel needs of populations. New constructions (e.g., residential buildings, industrial and commercial areas, large sports and leisure facilities) are often accompanied by the construction of new transport networks such as roads or railways. These infrastructures can have significant impacts on ecosystems, both by its physical footprint and its traffic flows (Jaarsma et al., 2013). These constructions favour the spatial process of landscape fragmentation that will affect the habitat patches of animal species by reducing their size or increasing their isolation (Fahrig, 2003). This process decreases landscape permeability, making wildlife movements and gene flow more difficult (Forman, Alexander, 1998; Cushman, 2006). The development of landscape ecology in the 1980s led to an increasing number of studies focusing on the ecological impacts of artificialisation on the landscape. The construction of newly built areas can create a barrier effect for species movement (Marull, Mallarach, 2005). However, this kind of fragmentation (sprawl) can be partially mitigated by the possibility of species movement in the interstitial zones of the urban development. The barrier effect depends on the shape and intensity of urbanisation (Alberti, 2005) and is generally intensified in the case of compact and dense cities (Tannier et al., 2016). In terms of transport infrastructure, fragmentation occurs by disconnection and reinforces the barrier effect, often over several tens of kilometres (Forman, Alexander, 1998; Fu et al., 2010; Girardet et al., 2013). Coffin (2007) points out that roads can have significant impacts on all ecosystems: abiotic ecosystem components (hydrological flows, sedimentary flows, water quality, pollutants) and biotic ecosystem components (disruption of animal movements, barrier effects). One of the major effects of roads on landscapes is caused by the direct transformation of natural and agricultural areas into artificial areas (Angelsen, Kaimowitz, 1999). Roads, particularly major infrastructures such as highways, are generally fenced for safety reasons. Traffic volume and speed can make these infrastructures difficult to cross for terrestrial species (Marsh et al., 2008; Holderegger, Di Giulio, 2010; Jaarsma et al., 2013), and can also affect diversity and abundance of other species such as birds (Rashidi et al., 2019). If the roads are crossable, the collision risk is significant for some species and may depend on several factors, such as road traffic, time of day, species behaviour, species size or the abundance of populations in the area (Fahrig, Rytwinski, 2009). This barrier effect of roads can be increased by a change in the behaviour of individuals who can learn to avoid roads in some cases (e.g., Reijnen, Foppen, 2006; Roedenbeck, Voser, 2008). For road networks, fragmentation by cut-off, often over several tens of kilometres, leads to a decrease in habitat quality and a reduction in ecological connectivity (Theobald et al., 1997; Carr et al., 2002). Following the definition proposed by Taylor et al. (1993), ecological connectivity is 'the degree to which the landscape facilitates or impedes movement among resource patches'. Thus, the reduction in ecological connectivity caused by the construction of new transport infrastructure can lead to a significant reduction in biodiversity and ecosystem change on a broader scale (Forman et al., 2003). The preservation of ecological connectivity, and by extension, that of ecological networks, is therefore essential to maintain the movement of animal species between their habitats. The issue of ecological network building and modelling is crucial to create territorial systems of ecological stability (Izakovičová, Świąder, 2017) and to assess the impacts of artificialized areas on ecological connectivity.

Since the 2000s, methods from landscape ecology and graph theory have been used to model the ecological networks of animal species as landscape graphs (Galpern et al., 2011). To assess the functional connectivity of landscapes, the landscape graph approach provides a suitable compromise between the quantity and precision of data required for the analysis and their capacity to represent ecological flows (Calabrese, Fagan, 2004; Urban et al., 2009). This method makes it possible to quantify connectivity by measuring it using spatial metrics (Rayfield et al., 2011). Some studies have focused on a retrospective approach by assessing connectivity losses caused by the construction of major transport infrastructures (e.g., Fu et al., 2010; Clauzel et al., 2013; Girardet et al., 2013). Other studies have used a prospective approach by assessing the potential impact of different land-use planning scenarios, such as the construction of a new highway (Vasas et al., 2009) or new residential development areas (Tannier et al., 2012, 2016). These studies have focused on the overall impact of a development or major transport infrastructure on a regional scale (calculation of a global connectivity metric) or habitat patches (calculation of a local metric). However, few studies have attempted to spatialise the potential connectivity of several animal species at any point in the territory. This kind of approach has been explored by Sahraoui et al. (2017) by assessing the retrospective impact of different land use changes. Currently, very few studies use this type of spatial representation to assess the ecological impact of future development projects. On the basis of these statements, our work aims to answer two main questions:

- How do we assess the potential ecological impact of a new highway using landscape graphs for several animal species?
- How can these results be spatially represented to make them explicit and usable for the scientific community and the general public?

To answer these questions, we proceeded in three steps: (1) modelling of ecological networks for a panel of animal species and computation of connectivity metrics in the initial state (before construction of the highway) and in the final state (after construction of the highway), (2) spatial generalisation of connectivity metrics for mapping the potential impacts of the highway on ecological connectivity and (3) reflexive feedback from comments on these results by the general public during a mobilisation day against the highway project.

Material and methods

Context

The context of this study is the construction project of a new highway aimed at linking the cities of Lyon and Saint-Étienne in France (Fig. 1). This area is concerned with strong demographic growth, with 60,000 to 65,000 new inhabitants expected by 2030 in the 25 municipalities crossed by the highway (15% increase in the population). Home-to-work and road transit cannot currently be fully absorbed by the existing railway line and the A47 highway, the fastest way to connect Lyon to Saint-Étienne by road. This new highway project, called 'A45', aims to strengthen exchanges between the two cities and reduce heavy traffic and the many existing traffic jams on the A47 highway.

The planned route of this new highway project is highly controversial for several reasons:

- it is very expensive: for a length of 48 kilometres, four tunnels and eleven viaducts would be necessary;
- it crosses many agricultural areas with high added value (organic farming, short-circuit agricultural production, etc.);
- it threatens several areas of high environmental value, including wetlands;
- it would not provide an efficient local service for people travelling *via* the A47 between the municipalities crossed by the highway, despite the 3 to 5 interchanges planned. Indeed, the Lyon-Saint-Étienne journey is not always carried out in its entirety by the local population;
- the cost of its toll is too high to allow local inhabitants to use it on a daily basis to travel.

Starting from these issues, mobilisation groups against the highway project (including local farmers, naturalists and residents) organised themselves to fight against this project. In this context, the aim of our work is to raise awareness among the local residents and politicians of the potential ecological impacts of this highway project.

Land-cover map of the study area

To model the ecological networks of several animal species, the first step in this work was to create an exhaustive land-cover map of the study area. There is currently no exhaustive database in France to determine all land use classes on a small scale. To do this, we used several regional, French and European databases. In each case, the most recent available database was used. The most accurate and widely used database is the BD Topo®, provided by the French Geographical Institute (IGN). By compiling these various databases, we created a land-cover map with 26 land-cover classes (Table 1). Figure 1 shows the resulting map with a simplified legend. The land-cover classes provided in vector mode were converted to a raster map with a 10 m resolution. This high resolution is necessary to take into account fine linear elements such as roads, small rivers or hedges.

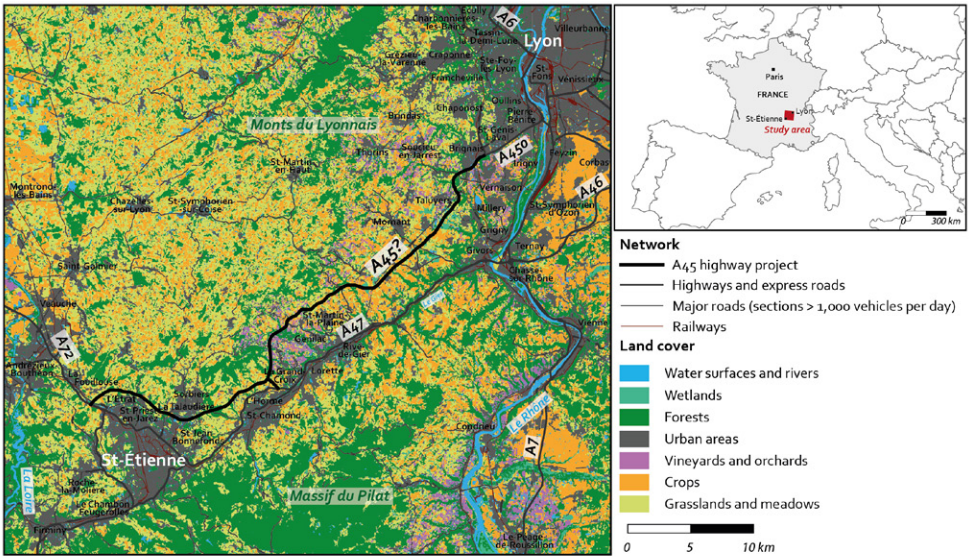


Fig. 1. Land cover map of the study area.

Target species

Since it seems too simplistic to focus on only one target species (Lindenmayer et al., 2000), we wished to implement a multi-species approach to take into account a representative panel of species in the study area, whether they are ordinary or rare. For this, we reproduced the methodology proposed by Sahraoui et al. (2017) by selecting the species present in the study area, defining their ecological traits and then creating species groups with similar traits. The selection of species present in the study area was made using presence data collected by volunteer naturalists of a wildlife association (LPO Rhône and LPO Loire). These presence data were collected in April 2018 on the websites https://www.faune-rhone.org/ and https://www.faune-loire.org/. In the study area, 426 different species were observed and recorded in the database. Species present in only one municipality in the area were excluded. If a species was present in at least 5 municipalities in the area and well distributed over the territory, it was kept for analysis. We considered that in this case, the species can move and use ecological networks to reach its different potential habitat patches. If a species had been observed only in a few adjacent communes, we excluded it from the study because we considered that given the field observation bias, it could be the same individual. As a result of these filters, 169 species were included. Then, these species were grouped according to three criteria: their taxonomic group, their dispersal distance and their main habitat (identified from the data from the National Institute of Natural Heritage, INPN). The dispersal distances of the species have been identified in the scientific literature, for example, from Smith and Green (2005) for amphibians and reptiles. If the information was not available, especially for birds and mammal, the dispersal distance was estimated from allometric relationships (Sutherland et al., 2000), taking into account the weight of the species, its taxonomic group and its diet as in Sahraoui et al. (2017). The species were then grouped into fifteen groups taking into account their preferred habitat and dispersal distance (Table 2).

Note: *The graphical parcel register (Registre Parcellaire Graphique) is a database of farmers' declarations for European subsidies. It is therefore very precise when it is filled in but is often incomplete. In this case, we completed

Table 1. List of categories, data sources, and processes used to construct the land-cover map of the study area.

Land-cover class	Data sources	Processing performed
Buildings	BD Topo® IGN (2017)	-
Urban areas	European Urban Atlas (2012)	For urban areas built between 2012 and 2017, a 50 m dilation-erosion was made around artificial areas (buildings, car parks, industrial areas, etc.) to recreate urban areas not defined in the European Urban Atlas
Planned route for the A45 highway	Greater Lyon	Digitising the route from a plan
Major roads	BD Topo® IGN (2017)	-
Secondary roads	BD Topo® IGN (2017)	-
Bridges	BD Topo® IGN (2017)	GIS processing: intersection between roads and rivers
High-speed railways	BD Topo® IGN (2017)	-
Railways	BD Topo® IGN (2017)	-
Rivers	BD Topo® IGN (2017)	-
Water surfaces	BD Topo® IGN (2017)	-
Wetlands	DREAL Auvergne-Rhône-Alpes	
Coniferous forests	BD Forêt® (2014)	-
Mixed forests	BD Forêt® (2014)	-
Deciduous forests	BD Forêt® (2014)	-
Groves	BD Topo® IGN (2017)	Selection of vegetation areas between 500 and 5,000 m²
Hedges	BD Topo® IGN (2017)	Extraction of hedges and edges from forest areas by morphological spatial pattern analysis (MSPA) (Vogt et al., 2007)
Edges	BD Topo® IGN (2017)	
Crops	Registre Parcellaire Graphique* (2016), OSO map (2017) (CESBIO, Toulouse)	-
Grassland and meadows	Registre Parcellaire Graphique* (2016), OSO map (2017) (CESBIO, Toulouse)	-
Moors	BD Topo® IGN (2017), Registre Parcellaire Graphique* (2016)	-
Lawns	BD Forêt® (2014), OSO map (2017) (CESBIO, Toulouse)	-
Orchards	BD Topo® IGN (2017), Registre Parcellaire Graphique* (2016), OSO map (2017) (CESBIO, Toulouse)	-
Vineyards	BD Topo® IGN (2017), Registre Parcellaire Graphique* (2016), OSO map (2017) (CESBIO, Toulouse)	-
Intraurban shrub vegetation	European Urban Atlas (2012)	-
Intraurban herbaceous vegetation	European Urban Atlas (2012)	-
Bare ground	-	The few pixels remaining after assembling the different databases were qualified as 'bare ground'. This often corresponds to interstitial spaces due to various database sources.

the information with the OSO map (Inglada et al., 2017) produced by remote sensing by the CESBIO laboratory (Toulouse, France). This database may contain some errors but remains much more accurate than CORINE Land Cover.

Attribution of movement costs

Each land-cover class is characterised by its capacity to facilitate or impede movements of species between their habitat patches. Following the method proposed in a previous work by Tannier et al. (2016), costs are attributed to the different classes of the landscape matrix according to their resistance to species movements as the following cost units: habitat (1), suitable (10), unfavourable (100), very unfavourable (1,000), and barrier (10,000). These costs were estimated for all 169 species present in each group based on the information available in the literature on individual behaviour. According to the value scales proposed by Gurrutxaga et al. (2010), the cost value of each road section varies between 100 (1,000 vehicles/day) and 1,000 (60,000 vehicles/day).

Table 2. Presentation of the fifteen species groups selected for the study.

Code of the species group	**Preferential habitat of the species group**	**Main taxonomic group**	**Dispersal distance (short : 0 to 1 km, medium : 1 to 10 km, long : 10 to 100 km)**	**Examples of species present in each species group**
1	Aquatic and forest environment	Amphibians	Short	*Lissotriton helveticus, Pelophylax ridibundus*
2	Aquatic and wetlands environment	Amphibians, mammals	Medium	*Bombina variegata, Ichthyosaura alpestris, Lutra lutra*
3	Aquatic environments	Birds	Long	*Ardea cinerea, Pandion haliaetus, Alcedo atthis*
4	Wetlands	Amphibians	Short	*Salamandra salamandra, Rana dalmatina*
5	Wetlands	Reptiles, birds	Medium	*Natrix natrix, Anthus pratensis*
6	Wetlands close to forests	Birds	Long	*Scolopax rusticola, Tringa ochropus*
7	Wetlands close to open environments	Birds	Long	*Circus pygargus, Milvus migrans*
8	Forests	Mammals	Medium	*Sciurus vulgaris, Martes martes, Capreolus capreolus*
9	Forests	Birds	Medium	*Dendrocopos minor, Strix aluco, Periparus ater*
10	Forests	Birds	Long	*Asio otus, Parus major*
11	Open environments	Insects, reptiles	Short	*Maniola jurtina, Podarcis muralis*
12	Open environments	Birds	Medium	*Ficedula hypoleuca, Phylloscopus collybita*
13	Open environments	Birds	Long	*Alauda arvensis, Tyto alba*
14	Semi-open environments	Birds	Medium	*Emberiza cirlus, Caprimulgus europaeus*
15	Semi-open environments	Birds	Long	*Phylloscopus bonelli, Hippolais polyglotta*

These costs are attributed in the case of species that can cross high-traffic roads (e.g., some bird species). As the roads in the study area are often fenced and difficult to cross for terrestrial species, we have reinforced the importance of roads for those species by keeping the same scale of values:

- 1,000 to 5,000 vehicles/day: cost between 1,000 and 3,000;
- 5,000 to 10,000 vehicles/day: cost between 3,000 and 7,000;
- 10,000 to 20,000 vehicles/day: cost between 7,000 and 8,000;
- 20,000 to 60,000 vehicles/day: cost between 8,000 and 10,000;
- More than 60,000 vehicles/day: cost of 10,000.

This empirical cost attribution method may be criticisable by specialists of each species, but it has the advantage of freeing us from collecting long and costly field data. For this reason, this cost attribution system is frequently used in landscape ecology studies (e.g., Verbeylen et al., 2003; Gurrutxaga et al., 2011; Clauzel et al., 2013; Bourgeois et al., 2018). The final cost assigned to each land-cover class for one species group is the average of the costs assigned for this land-cover class for all the species of this group.

Construction of graphs

A landscape graph is a set of nodes and links used to model the ecological networks of each species group; nodes represent habitat patches, and links represent possible movements between these patches. Patches are extracted from land-cover classes. For example, for a forest species, habitat patches are land-cover pixels of the 'forest' type. For each species group, we did not define a minimum area of habitat patches. The links between habitat patches are represented by the average dispersal distance of each species group and converted into cost distance. The links represent the least-cost paths between each habitat patch and are thresholded by the dispersal distance of the species group studied. Thirty landscape graphs were generated for this work: fifteen in the initial state (one for each species group) and fifteen in the final state, after adding the A45 highway to the land-cover map. Landscape graphs were computed with Graphab 2.4 software (Foltête et al., 2012).

Computation of connectivity metrics

The construction of landscape graphs allows the calculation of connectivity metrics to quantify ecological connectivity for the entire graph (global metric) or for each habitat spot (local metric). The global metric used here is the equivalent connectivity (*EC*) (Saura et al., 2011), characterising the connectivity potential across the entire ecological network and measured as follows:

$$EC = \sqrt{\sum_{i=1}^{n}\sum_{j=1}^{n} a_i a_j e^{-\alpha d_{ij}}}$$

where *n* is the total number of patches, a_i and a_j are the areas of patches *i* and *j*, and is the maximum probability of potential paths between *i* and *j*. was calculated with an exponential function such that:

$$p_{ij} = e^{-\alpha d_{ij}}$$

where d_{ij} is the least-cost distance between *i* and *j*, and α (0 < α < 1) expresses the intensity of decreasing probability of dispersion resulting from the exponential function.

To quantify the loss of connectivity at the scale of each habitat patch, we chose the local metric interaction flux (*IF)* (Foltête et al., 2014; Sahraoui et al., 2017), which is the local contribution of each patch to the global *EC* metric. For a given patch, *i*, is given by:

$$IF_i = \sum_{j=1}^{n} a_i^{\beta} a_j^{\beta} e^{-\alpha d_{ij}}$$

where *n* is the total number of patches, a_i and a_j are the areas of patches *i* and *j*, and is the maximum probability of potential paths between *i* and *j*.

Unlike the global *EC* metric, the computation of this metric allows us to spatialise connectivity for each habitat patch. The main disadvantage is that connectivity values are only computed for habitat patches, making comparisons difficult for species groups with patches of different habitats (e.g., forest habitats and wetland habitats).

To do this, we reproduced the approach proposed by Sahraoui et al. (2017) to evaluate the potential accessibility of any point (i.e., pixel) of the overall study area on the landscape graph of several species groups. In our case and for a given group, the patch-level connectivity value (*IF*) was used. This spatial generalisation relies on the assumption that individuals may be found outside habitat patches, although with a lower probability than being found within their habitat patches (Hirzel, Le Lay, 2008). Based on this assumption, (1) a given point located outside the patches was considered potentially connected to the habitat network by inheriting the connectivity levels from the surrounding patches, and (2) the influence of a patch towards a point should decrease with distance, so that the farther the point from the ecological network, the lower its potential connectivity. The weighting function designed to represent this distance effect is identical to that used to compute the *EC* index, that is, the negative exponential function where is the weight of a patch with respect to a point located at a least-cost distance *d*. For a given point, connectivity levels from several patches were attributed by summing the weighted values of *IF* as follows by taking into account least-cost distances:

$$gIF(i)_i = \sum_{j=1}^{n} IF_{(j)} \times \omega_{ij}$$

where is the generalised value of *IF* for point *i*, and is the weighting of patch *j* for point *i*.

As a result, we obtained for each species group a 10 m resolution map in the initial state and in the final state (after adding the highway), on which each pixel took on a value corresponding to its potential of connectivity to the overall network. For each of the species groups, a new map was created, resulting from the calculation of the rate of change between the initial and final state for each pixel of the map.

Results

Global connectivity assessment

The average estimated change in global connectivity for each species group is -2.53% in the *EC* metric. However, this average is difficult to interpret because the ecological connectivity losses are very different between each species group (see Fig. 2).

We did not observe a direct link between the main habitat class and the observed impacts, suggesting a stronger role of movement behaviour. For example, the connectivity of species group n°5 is significantly affected by the highway project since the planned route cuts through many wetlands that support the habitat and movement of the species concerned. Conversely, the impact of the highway is almost zero for species group n°1, whose habitats and potential movement areas are very distant from the route.

Local connectivity assessment

With spatial generalisation of local connectivity metrics, we designed fifteen maps spatialising the impact of the highway on functional connectivity for each species group studied, for example, for species group n°5 and n°12, whose main habitats and global impacts are differentiated (Fig. 3). For both groups, our results showed a strong impact in the area between the existing A47 highway and the future A45 highway. This result can be explained by the fact that the A47 highway, built in parallel with industrial areas and a river, is already a strong barrier to the movement of species,

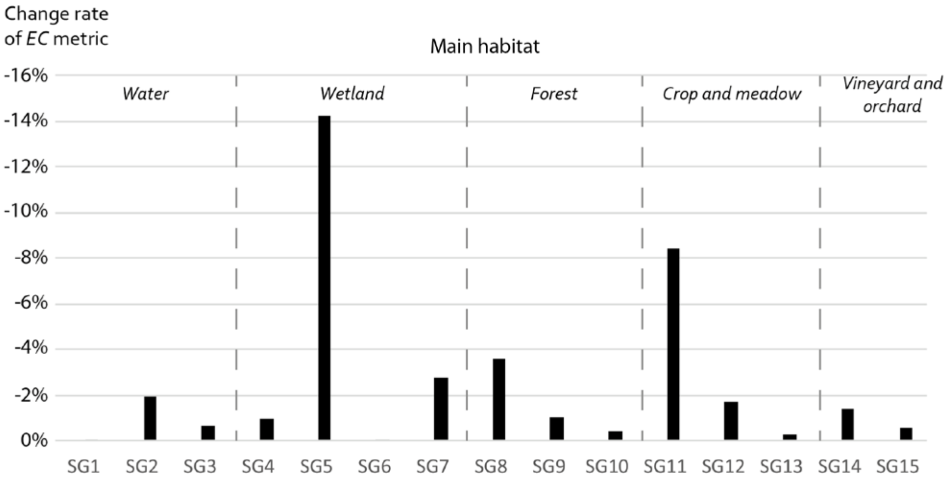


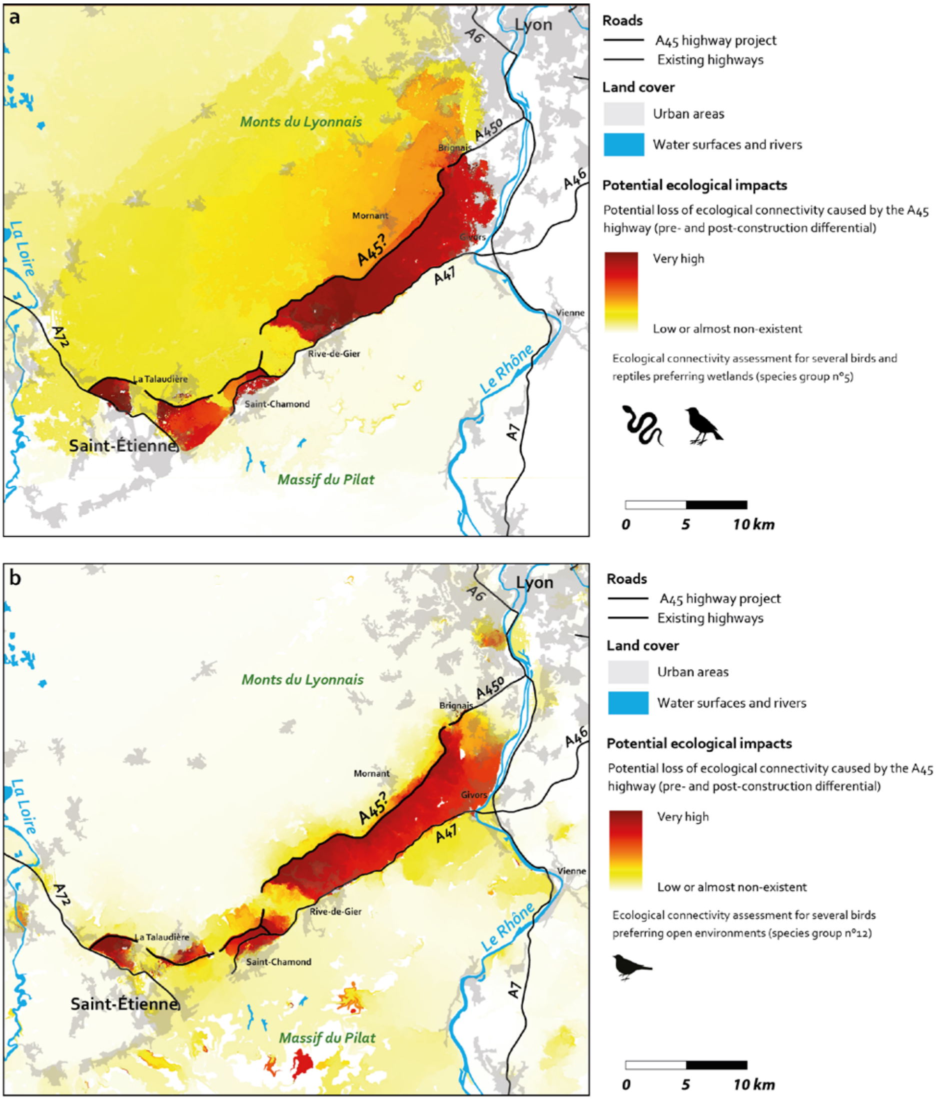
Fig. 2. Assessment of loss of connectivity for the entire study area. The change rate of the *EC* index is computed with an assessment of connectivity at the initial state (before construction of the highway) and the final state (after construction of the highway). SG means 'species group', and the number is the code of each species group detailed in Table 2.

including flying species. The construction of the highway would tend to create a new barrier in the north and drastically reduce ecological connectivity in the area between the two highways. However, the A45 project also affects connectivity away from the highway path. In the case of the group n°5, the impact values remaining high in the north of the A45 project, gradually decreasing with distance. For the group n°12, the impacts are however stronger in the southern part, with isolated very high impacts in the hearth of the *Massif du Pilat*.

These mapping results were then formatted and printed on A0 posters to be presented to the general public during a day of mobilisation against the A45 highway in La Talaudière (a small town near Saint-Étienne). This event, which took place on 22 September 2018, brought together nearly 3,000 people (general public and local elected officials), mainly against the highway project. The presentation of the mapping results in workshops during the day (see Fig. 4), accompanied by explanations of the concept of ecological connectivity, opened the debate on the potential ecological impacts of the highway among approximately one hundred people who participated in the workshops.

Discussion and conclusion

This work was made possible by an effective reuse of methods presented in other works to assess the ecological impact of land use planning projects or land-cover changes (e.g., Girardet et al., 2013; Mimet et al., 2016; Tannier et al., 2016; Sahraoui et al., 2017). The construction of a fine-scale land use map and the implementation of a multi-species approach have enabled the modelling of landscape graphs. Based on these graphs, the calculation of global and local connectivity metrics allowed us to assess the potential impacts of the A45 highway project on a set of species representative of the different natural environments crossed by this project. Although global con-



Sources : BD Topo IGN 2018, bibliographic corpus listing information on species preferences
Computations with the Graphab software: Marc Bourgeois (UMR EVS, University Lyon 3) and Gilles Vuidel (UMR ThéMA, University of Bourgogne-Franche-Comté)

Fig. 3. Map of the potential impacts of the A45 highway on functional connectivity for species group n°5 (a) and species group n°12 (b).

nectivity metrics (i.e., for an entire study area) have been useful in comparing the sensitivity of species groups to the highway project, they only provide an overview of the impacts. The main limitation of these results lies in the lack of information on the location of the impacts. The spatial generalisation of local connectivity metrics allowed us to overcome this limitation. From this, several maps of the impacts of the highway project were produced and presented during a day of

Fig. 4. Workshop and debates around connectivity maps during a mobilisation day at La Talaudière (22 September 2018).

mobilisation against the project. These discussions made it possible to evaluate the reception by a neophyte public of geographical information produced as part of a research process.

First, workshop participants were often surprised by the spatial extent of the impacts of the highway project. Indeed, naturalist collectives are often used to present the impacts of the highway in the immediate environment of the route, while our maps (e.g., Fig. 3b) show impacts far from the infrastructure (up to 15–20 km in some cases). For example, we can observe a significant loss of connectivity in the south of the area (Pilat massif) at a significant distance from the route. However, these remote impacts were difficult for some people to understand, but they were useful in highlighting and explaining the concept of ecological networks. We also presented a map to show the highest connectivity loss for each of the species groups. This map, resulting from the combination of the fifteen maps produced, showed results that were more difficult to understand for the public and required more explanations. An *a priori* scientific mediation, therefore, seems necessary to support the public in the interpretation of the results. Other maps, more understandable to the public, were also presented during the day. Some of them showed the expected changes in urbanisation in the municipalities near the route (spatialization of the future areas to be urbanised and the expected variation in the population of each municipality in the study area). These maps are not directly related to the ecological impacts of the highway project but have made people aware of the need to find new medium-term mobility solutions instead of this new highway.

One of the major limitations of this study is that many data processing operations were necessary to prepare these results. To produce these maps in a limited time, we had to make many choices, many of which can be criticised from a scientific point of view (representation of land use classes, choice of species, allocation of costs, for example). However, these choices were necessary to model the ecological connectivity over a study area of several tens of square kilometres. Despite our explanations during the workshops, the understanding and interpretation of the results can be biased by the 'black box' effect of the processes. To overcome this problem, it would be appropriate to involve participants at different stages of the modelling process from a participatory modelling perspective.

Finally, people were mainly satisfied to observe that the highway project could have a significant impact on ecological connectivity on a large scale, legitimising their fight against the highway route using nature conservation arguments. While spatial modelling tools are generally used in a decision-making context with political decision-makers and planners, this work opens the door to the use of spatial modelling in the context of citizen mobilisation.

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