Monitoring of the Recreation Effects on Land Cover with the Use of an Unmanned Aerial Vehicle on the Example of the Strelnaya Mountain in Samara Region

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***Abstract*—Strelnaya Mountain is one of the objects most exposed to recreational stress in the Zhigulevsky State Nature Reserve. Until recently, monitoring studies of the recreational pressure carried out by university staff have been limited to either inspecting plant communities from the metal decking installed on the trace, or descending to the surface of the slope and move along it with the risk of injuring vulnerable vegetation cover. The use of unmanned aerial vehicles (UAVs) opens up new prospects for quick and efficient identification of points affected by recreational exposure, including those remote from the floor, without contacting the slope surface. The first experience of integrating ground-based and UAV-based monitoring was carried out in 2019. We shot the Strelnaya Mountain in spring and autumn using UAVs. The obtained images were classified using the support vector machines method with radial basis functions into "trace" and "non-trace" classes. As a result, it was possible to automatically select trampled slope sections with a high degree of accuracy. The preliminary results of the work are presented.**

Keywords—remote sensing images, unmanned aerial vehicles, trace classification

I. INTRODUCTION

The society interest in wildlife objects, including those confined to specially protected territories of various statuses, demonstrates growth in the wideworld. The protected areas, characterized in natural heritage objects richness, are greatly important in terms of biological diversity and other valuable nature components conservation. This circumstance imposes restrictions associated with proactive planning of conservation measures on the forms of ecotourism organization [1].

Zhiguli Mountains, having relatively small values of the area and absolute heigh, sufficiently demonstrate the plant communities mosaic structure inherent in mountain ecosystems themselves, and the vertical zonality is traced here much weaker. The combination of natural complexes within the Zhigulevsky State Reserve boundaries contains a unique formation of plants, animals, lichens, including endemic and relict species In particular, 178 out of 1022 vascular plants species of the reserve flora are of special scientific importance, including endemics - 27 (5 narrow Zhiguli endemics), relics - 46, included in the Red Book - 17, described for the first time from the reserve - 16 species and 5 varieties [2]. Here, the presence of 229 bird species (about 80% of the Samara region avifauna) was reliably established, 150 species are regularly found on the territory and at the borders of the reserve. The fauna of mammals includes 48 species belonging to 6 orders, 15 families, and 34 genera (about 63% of the number of Samara region mammalian species). The invertebrate fauna of the reserve includes more than 7 thousand species, among which 14 species are recognized as rare and included in the Red Book of the Russian Federation, 120 species are in the Red Book of the Samara Region [3, 4].

The Strelnaya Mountain is one of the sites of the Zhigulevsky state reserve most exposed to recreational pressure. The high conservation value of Strelnaya Mountain is determined by the fact that it presents almost all the phytocenotic and floristic diversity of the rocky steppes - relict plant communities of Zhiguli, which are adjoined by mountain oak forests and pine forests. Starting from the 50s of the XX century, a trail-path network was formed on Strelnaya Mount in consequence to oil production in Zhiguli during the war years. Since 1966, in the revival reserve, the free visits restriction to the mountains was introduced. An excursions practice for tourists took its beginning these years, since that an excursion route has been operating here. According to many years of Zhigulevsky Reserve employees research carried out in the pedestrian area of the excursion route (1983-2008), natural communities underwent a marked transformation and degradation in the result of the recreational impact. The path network expanded, the area of knocked-out areas increased, the land cover was locally destroyed on the slopes along the path, significant changes in the composition and structure of communities occurred.

In recent decades the population interest in visiting natural heritage unique places has significantly increased. That is why not only national parks that carry out ecotourism activities according to their status [5] but also state reserves are faced with the task to organize a regulated visit to their territory taking into account the permissible recreational load and minimizing damage to natural communities.

In 2012, a metal hiking trail flooring with a railing was installed, expanding on the stony slope in the form of an observation platform, where the information stands located. At the top of the mountain, the flooring forms a large viewing platform, which is raised on the supports in front of the mountain to a height exceeding the height of the peak (Fig. 1). This construction aims to prevent the ability of visitors to walk freely along the vulnerable mountain slopes. Since 2013, on the entrustment of the Zhiguli State Reserve direction, specialists from the Chair of Ecology, Botany and Nature Protection of Samara University have been conducting monitoring studies to identify possible ecosystems changes after the excursion trail arranging.

The named excursion trail flooring was supposed to minimize the negative recreation impact on natural ecosystems with a significant increase in the accepted tourists flow, and natural overgrowth during the self-healing of plant groups was expected to restore vegetation cover in areas disturbed during its construction. Monitoring studies were aimed to establish whether the vegetation cover disturbed earlier (with the existence of a pedestrian path or during the construction) is adequately restored, which species are restoration participants, and whether the new trail fully performs its environmental functions.

Fig. 1. General view of the parts of excursion trail flooring in Strelnaya Mountain.

The implementation of ground-based monitoring studies in Strelnaya Mountain allowed us to identify a basic list of vascular plant species that form plant associations, as well as ruderal species. The vegetation cover disturbed during the construction of the flooring is restored under the flooring due to the growth of individuals located near the flooring and the development of new seedlings from soil seed bank. The degree of trampling has increased. Jumping from the floor in front of the supports of the observation deck, visitors break the substrate and destroy the plants, disruption of the substrate connectivity provokes an increase in soil washout by rain and melt water. In place of mountain steppe perennials damaged by trampling, the local invasions of various ruderal (weed) plants was noted.

Using visual fixation of the vegetation cover state on the trial plots during field surveys, we found that new paths appear on the sides of the excursion floor and the existing ones expand in the result of chronic rules violation by visitors on the excursion trail. In parallel with the emergence of new hiking trails along the floor, overgrowth and disappearance of paths that lost attractiveness for visitors take place, but the movement along the slope has become spatially more pronounced. The restoration of previously disturbed plant communities occurs unambiguously where there are areas inaccessible to visitors - under the floor. The species involved in the vegetation renewal of disturbed areas show an alternation of their presence and abundance, which can be considered a reflection of the cenopopulations development features. The excursion route visitors increasingly use mountain slopes for selfies and mini-picnics behind the viewing platform. The pressure on it has become higher last year than it was before the flooring device (Fig. 2).

Fig. 2. Warning plate and violation of the conduct rules by visitors on the Strelnaya Mountain.

II. The use of UAVs in monitoring of recreational pressure effect on the plant cover state in Strelnaya Mountain

The plant cover monitoring is traditionally based on ground surveys. Its advantages are detailed description (high spatial resolution, in fact, with the coverage of single plant specimens on the trial plots) and the high significance of the information received. On the other side, field surveys always have a limited area coverage, large in the case of studies during routes, and much smaller when using long-term stationary sites. The results of field surveys often do not allow accurate data extrapolation to the entire landscape, especially if the objects of interest are distributed not evenly. Another disadvantage of using traditional field studies is that they require significant time and efforts investments to cover large areas [6].

On the contrary, methods based on remote sensing (RS) provide data collection over large spatial limits and are less time-consuming than traditional ground surveys. Various optical systems (IKONOS, Quickbird, RapidEye, etc.) can provide images with very high resolution of fewer than five meters per pixel [7, 8]. However, many remote sensing products are very expensive to obtain, while free data available from the satellites of NASA Landsat series and the Sentinel missions of the European Space Agency have a low spatial resolution and, therefore, are limited, for example, to changes in the earth cover and habitat mapping [9, 10].

The contradiction between the capabilities of remote sensing materials and the need for detailed natural ecosystems picture can be eliminated in certain respects due to the emergence of a new segment of RS - small unmanned aerial vehicles (UAVs), or drones that were originally developed and used primarily in the military and defense industries. Their development, according to experts, led to the appearance of the so-called dronosphere [11], the space between the levels of manned air activity and the earth surface. The boundaries of the dronosphere currently depend on technical characteristics and rules, but they usually include direct proximity to the earth. Currently, the rapid development of UAVs makes them more accessible for many research purposes. In particular, data obtained using UAVs can provide digital images without clouds and with very high resolution for vegetation monitoring at the landscape level or characterizing small-scale landscapes [12]. There is monitoring experience using UAV surveys of protected plant populations [13].

Monitoring of the recreational effect on Strelnaya Mountain in ground-based organisation forms for several years was limited by the inspection of plant communities from the excursion trail flooring, which made it possible to assess the plant populations state in close proximity to it, or by moving on the slope surface with the injury risk of vulnerable vegetation cover and thin soil layer on the crushed stone substrate. The use of UAVs opens up new prospects for the remote, efficient, and quick identification of points affected by recreation exposure, including those remote from the floor, without contact with the slope surface. In 2019 (Fig. 3), test spring and autumn surveys of Strelnaya Mountain were carried out using UAVs.

The shooting was carried out with the help of the Phantom 4 PRO aircraft. Characteristics of the camera - 3 optical bands RGB, the resolution depends on the height of shooting: for spring shots the resolution is 0.0107m/pixel, for autumn shots - from 0.019 to 0.037 m/pixel (the territory was shot by three spans) [14]. Frames of one span were combined with DroneDeploy, the software for drones designed for automatic processing of the received data. Further, the spans were combined in a semi-handheld mode in ScanEx Image Processor v 4.2 application. The acquired images represent: in spring - the area of approximately 2700 m2, in autumn - the area of 88600 m2. Altitude difference was several tens of meters from the height of Mountain Strelnaya (351 meters above sea level).

The images obtained (Fig. 4) were analyzed for the possibility of automatic detection of illegal traces.

Fig. 3. Trial surveys of the excursion route on the Strelnaya Mountain and the adjacent sections of the slope using UAVs (May 27, October 3, 2019).

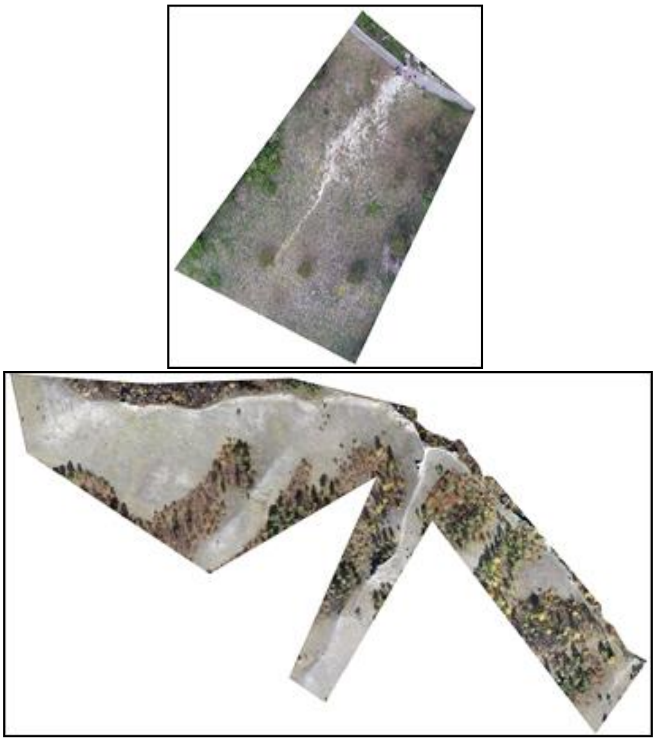


Fig. 4. Mountain Strelnaya UAV (from up to bottom): the photo captured on May 27, 2019, photo captured on October 3, 2019.

III. Trace classification using support vector machines with radial basis functions

To classify traces along the tour route in a conservation area, we applied a support vector machines method with radial basis functions (SVM RBF) implemented in software package Matlab R2017b. SVM RBF is frequently used for the two-class problem, especially in the case of nonlinear boundary between classes [15].

We provided a classification for two classes «trace» and «no trace». The outlier probability parameter of the classifier was set to 0.3. The training set for class «no trace» included small parts of background area such as grass, trees and the coverage of the tour route. For class «trace», training set included images of calcareous soil without grass. Calcareous rocks are the main component of the soil in the region of study. It has a white color that makes trace visually recognizable in RGB spectral range.

As for features, we applied a local average of RGB spectral channels in 3×3 pixels window. Averaging is used to suppress noise in the image before classification.

We included fragments of both images obtained in May and October into the training set because weather and lighting conditions were too different for both scenes. Moreover, the spectral response of vegetation was also different due to the different phenological characteristics of the plants during the growing stage in May and the senescence stage in October. For training and classification, we used normalized features with zero mean and unit variance. Normalization allows decreasing the impact of different brightness ranges in different spectral channels. The number of pixels in the training set was 7681: 1180 for class «trace» and 6501 for class «no trace». The example of features scattering plot for the training set is shown in Fig.5.

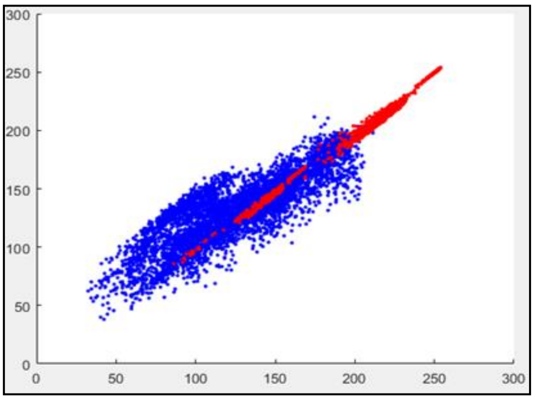


Fig. 5. Scattering plot of the training set: class «trace» - red dots, class «no trace» - blue dots.

Before training and classification, we applied decimation of UAV images in eight times. As a result, the images for classification had worse spatial resolution than the original UAV images. The necessity of decimation is explained by the data redundancy in terms of trace shape estimation and high computational load. The sampling ratio was selected as a maximum value for which traces can be visually recognized on the image.

We tested our classifier on parts of traces with different width. The test images were obtained from both UAV images. The classification results of one trace part are shown in Fig. 6.

In spring image there are more grass parts on the trace than in the autumn image where the trace looks more trodden. This confirms the assumption that this part of the slope is used for unauthorized tourist visits.

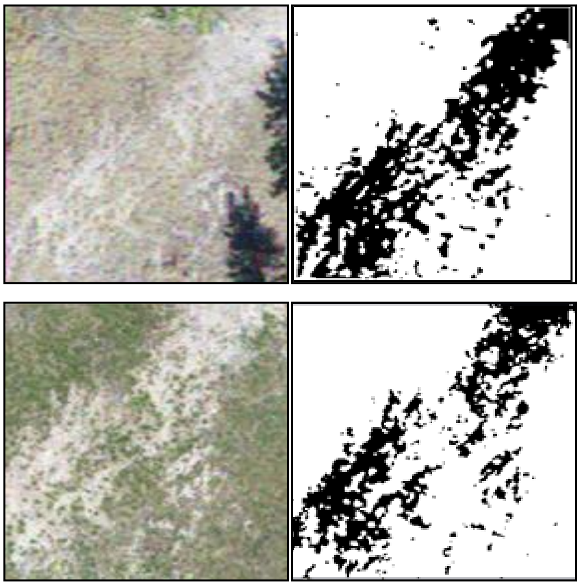


Fig. 6. The results of trace classification with the grass background (from left to right): autumn image, classification of the autumn image, spring image, classification of the spring image.

In most cases, classification results match to the reference data selected by experts. The classification result and its comparison with the experts' trace contour are shown in Fig.7. The automatically detected trace is a little wider than the experts' contour. To describe the trace classification accuracy we used the following measure (1):

$$Efficiency = \frac{S_a \cap S_e}{S_e}, \tag{1}$$

where S_a - the number of pixels classified as trace, S_e - the number of pixels selected as a trace by the expert. In this experiment trace classification accuracy was 87.5%.

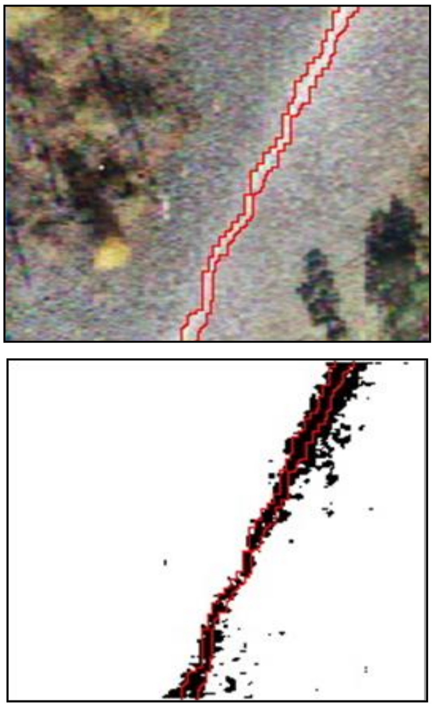
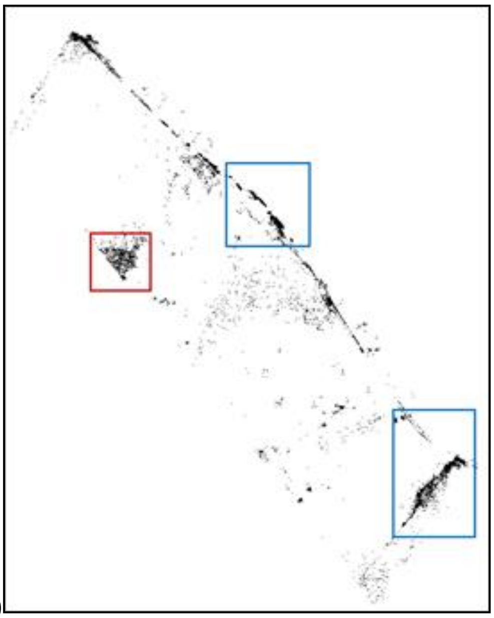


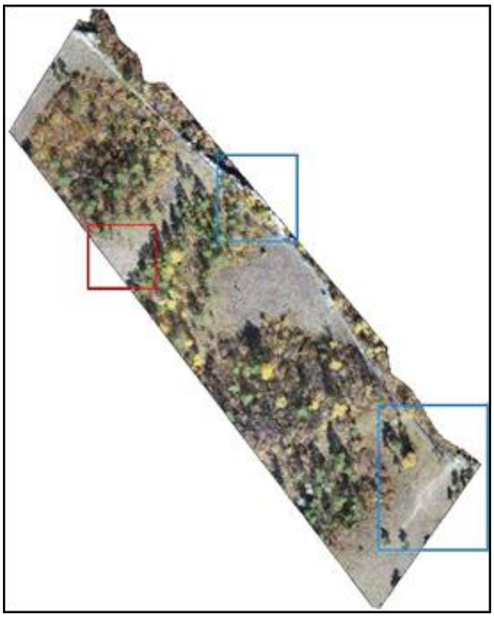
Fig. 7. Comparison of the trace classification with the reference trace contour (from up to bottom): autumn image with trace contour, classification result with trace contour.

The final experiment aimed to classify the entire region of interest to find unknown traces. As a result, the algorithm found trace parts which were not used in a training set. SVM-RBF classifier finds traces using simple brightness features in both autumn and spring images. However, bare slopes with the same type of soil are also classified as traces. Thus, further analysis of traces requires trace shape estimation using morphological filters of the classified images.

The classification results of autumn and spring images are shown in Fig. 8 and Fig. 9 correspondingly. Note, that the tour route coverage is not classified as trace because it is made of metal and it has the different spectral responses in RGB channels in comparison with trace.

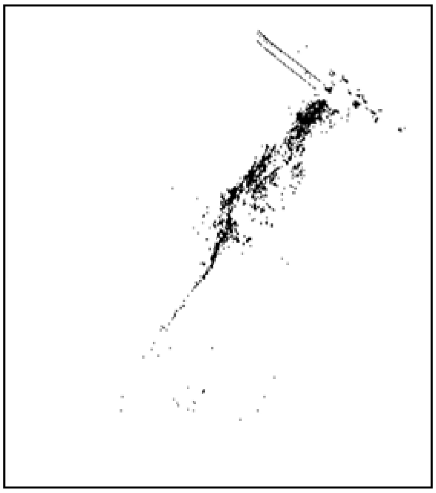


a)



b)

Fig. 8. Trace classification: a) classification result, b) autumn UAV image. Red square highlights false trace (it is a slope with bare calcareous soil). Blue squares indicate the largest of the side traces along the tour route.



a)

b)

Fig. 9. Trace classification: a) classification results, b) spring UAV image.

IV. Conclusion

The research aimed to find out how effective the use of UAV remote sensing for recreational stress monitoring on the example of Strelnaya Mountain. To detect traces we applied SVM-RBF classification. As a result, the classifier found the traces selected by the experts during the ground survey and additionally some parts of bare slopes that are the examples of false detection. But it can be considered a false detection only conditionally, as the algorithm was configured to search for trampled (naked, devoid of vegetation) soil. To reduce false detection the analysis of trace shape should be performed using morphological image filtration. Nevertheless, the trace classification gives successful results, in particularly, the trace detection shape accuracy was about 87.5%.

We also should say about one more task - determination of vegetation composition, both existing and arising. This task has not been solved yet. This is due to insufficient resolution even of such highly detailed images as UAV images, as well as the small number of data. It is planned to repeat surveying of Strelnaya Mountain several times a season (spring, autumn) at least several years to have observation statistics. Based on the obtained series of images it will be possible to try to identify large coalitions of vegetation using vegetation indices, which are widely used in analysis of remote sensing images [16, 17].

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REFERENCES

[1] P.Wight, “Planning for resource protection and tourism management in protected areas: A practical perspective,” Tourism: People, Places, Products, pp.130-141, 2002.

[2] State report on the state of the environment and natural resources of the Samara region for 2014, vol. 25, 2015.

[3] Red Book of the Russian Federation (plants and mushrooms), Moscow, Partnership of scientific publications of KMK, 2008.

[4] The Red Book of the Samara Region. Rare species of plants, lichens and fungi, Tolyatti: IEVB RAS, 2007.

[5] On Specially Protected Natural Areas: Feder. Law of March 14, 1995 No. 33-FZ: Ed. from Nov 24 2014. Meeting of the legislation of the Russian Federation, 1995.

[6] C.S. Shuman and R.F. Ambrose, “A comparison of remote sensing and ground-based methods for monitoring wetland restoration success,” Restor. Ecol., vol.11, pp. 325-333, 2003.

[7] T.W. Gillespie, G.M. Foody, D. Rocchini, A.P. Giorgi, and S. Saatchi, “Measuring and modelling biodiversity from space,” Prog Phys Geogr., vol. 32, pp. 203-221, 2008.

[8] K. Wang, S.E. Franklin, X. Guo and M. Cattet, “Remote sensing of ecology, biodiversity and conservation: a review from the perspective of remote sensing specialists,” Sensors, vol.10, pp. 9647-9667, 2010.

[9] E. Ostrom and H. Nagendra, “Insights on linking forests, trees, and people from the air, on the ground, and in the laboratory,” Proc. Natural. Acad. Sci. USA, vol.103, pp. 19224-19231, 2006.

[10] H. Nagendra and D.Rocchini, “High resolution satellite imagery for tropical biodiversity studies: the devil is in the detail,” Biodivers. Conserv., vol. 17, pp. 3431-3442, 2008.

[11] M. Germen, “Alternative cityscape visualisation: drone shooting as a new dimension in urban photography,” Electronic Visualisation and the Arts (EVA), pp. 150-157, 2016.

[12] G.P. Jones, L.G. Pearlstine and H.F. Percival, “An assessment of small unmanned aerial vehicles for wildlife research,” Wild. Soc. Bull., vol. 34, pp. 750-758, 2006.

[13] J.Y.L.Tay, A. Erfmeier and J.M. Kalwij, “Reaching new heights: can drones replace current methods to study plant population dynamics?” Plant Ecol., vol. 219, pp. 1139-1150, 2018.

[14] A.V. Nikonorov, M.V. Petrov, S.A. Bibikov, V.V. Kutikova, A.A. Morozov and N.L. Kazanskiy, “Image restoration in diffractive optical systems using deep learning and deconvolution,” Computer Optics, vol. 41, no. 6, pp. 875-887, 2017. DOI: 10.18287/2412-6179-2017-41-6-875-887.

[15] S.A. Bibikov, N.L. Kazanskiy and V.A. Fursov, “Vegetation type recognition in hyperspectral images using a conjugacy indicator,” Computer Optics, vol. 42, no. 5, pp. 846-854, 2018. DOI: 10.18287/2412-6179-2018-42-5-846-854.

[16] V.V. Efremenko and T.N. Chimitdoriev, “On the use of various vegetation indices in remote sensing of ecosystems,” Research of the Earth from space, pp. 49-56, 1988.

[17] N.S. Vorobiova, V.V. Sergeyev and A.V. Chernov, “Information technology of early crop identification by using satellite images,” Computer Optics, vol. 40, no., 6, pp. 929-938, 2016. DOI: 10.18287/2412-6179-2016-40-6-929-938.