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Is Artificial Light at Night Dangerous for the Balkan Strict Protected Areas at Present?

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Abstract The Balkan Peninsula has rich biodiversity with a large number of endemic species; therefore, a part of its territory has been recognized as a World Biodiversity Hotspot. Despite nature conservation efforts and development of nature conservation networks in countries of the region, anthropogenic influence on natural and semi natural ecosystems is increasing. Moreover, new types of disturbance and pollution arise, and one of the more recent being artificial light at night (ALAN) which has serious consequences on reproduction, navigation, foraging, habitat selection, communication, trophic and social interactions of the biota. We have estimated the level of ecological light pollution in the strict protected areas of the Republic of Serbia, the Republic of Bulgaria, and Montenegro using available Google Earth Pro tools, and the New World Atlas of Artificial Sky Brightness (2016) in the form of a kmz layer. The research has covered 13 National Parks, 11 Nature Parks and 55 Reserves. Our results showed widespread incursion of ALAN within strict protected areas in the studied region that has also been noted for some other countries and regions too. However, the level of light pollution is lower here, than in the most part of Continental Europe, and there are a few areas in each country where the night sky above National and Natural Parks is almost dark. These territories have a special value for nature conservation; therefore, it is important to save the dark night sky there.

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The Balkan Peninsula has rich biodiversity with a large number of endemic species (Griffiths and Kryštufek 2004; Petrova and Vladimirov 2010; Tomović et al. 2014; Vuksanović et al. 2016). That is why a part of its territory in borders of Mediterranean has been recognized as a World Biodiversity Hotspot (Mittermeier et al. 1999, 2005; Myers et al. 2000). There are 6 biogeographic regions located within the Balkans: Alpine, Black Sea, Continental, Mediterranean, Pannonian, and Steppic (European Commission 2019; European Environment Agency 2012). Despite nature conservation efforts and development of nature conservation networks like the Important Bird Area Network (Puzovič 2009; Velevski et al. 2010), the Important Plant Area Network (Angelova et al. 2012; Melovski et al. 2012; Nikolić 2009; Petrović 2009; Stevanović and Šinžar-Sekulić 2009), the NATURA 2000 Network (Gussev and Tzonev 2015; The Ministry of Environment and Water of Bulgaria 2014), and Emerald Network (Convention on the Conservation of European Wildlife and Natural Habitats 2008; Group of Experts for the setting up of the Emerald Network of Areas of Special Conservation Interest 2003, 2006; Prokić 2008) in countries of the region, anthropogenic influence to natural and semi natural ecosystems has been increasing for a long time (Griffiths and Kryštufek 2004; Kulakowski et al. 2017; Longman et al. 2018; Marinova et al. 2012; The European Environment Agency 2011). Moreover, new types of disturbance and pollution arise, one of the more recent pressures is artificial light at night (ALAN) that has already been noted for protected areas of autonomous province of Vojvodina in North Serbia (Bjelajac and Đerčan 2019).

Nowadays there is no exact data about the level of ALAN from which the impact on biodiversity starts (Falchi et al. 2016), but a lot of evidence about ALAN influence on reproduction, navigation, foraging, habitat selection, communication, trophic, and social interactions of the biota have already been discussed (Bennie et al. 2016; Dominoni et al. 2016; Gaston and Bennie 2014; Hölker et al. 2010b; Longcore and Rich 2004; Navara and Nelson 2007; Rich and Longcore 2006). For example, ALAN has been documented as a contributing factor to the global decline in insect populations (Grubisic et al. 2018; Hallmann et al. 2017; Leather 2018; Macgregor et al. 2015). Furthermore, ecological light pollution not only can cause cascading effects in ecosystems, restructuring ecological communities by modifying the interactions between species, and impacting pollination and seed dispersal (Bennie et al. 2015a), but also being a driver of evolution across urban-rural landscapes (Hopkins et al. 2018). Unfortunately, understanding of benefits which human society has from ALAN (Boyce 2019; Gaston et al. 2015b), as well as its dynamics (Cinzano et al. 2001; Falchi et al. 2016, 2019; Kyba et al. 2017) does not allow considering this disturbance factor as temporary or insignificant for species, especially nocturnal ones.

In this case, strict protected areas have a special value for biodiversity conservation because the impact of different anthropogenic factors is minimized there. It must concern ALAN too; however, it is not taken into account by either scientists or authority in the majority of countries. There are only few countries like Italy, which enforce laws against light pollution (Falchi 2018). Though the investigations of the level of ecological light pollution within protected areas of some countries and regions show its widespread incursion (Bjelajac and Đerčan 2019; Gaston et al. 2015a; Guetté et al. 2018; Jiang et al. 2017; Peregrym et al. 2018). Therefore, in view of the foregoing, it has been decided to estimate the level of ecological light pollution and its danger for strict protected areas (Nature Reserves, National and Nature Parks) of the Balkans as unique places for biodiversity conservation.

1 Material and Methods

The research covers strict protected areas of three Balkan countries: the Republic of Serbia, the Republic of Bulgaria, and Montenegro. The Republic of Serbia is considered together with Kosovo region because the Republic of Kosovo is a partially recognized state and disputed territory still, though the nature management of Šar planina National Park which is located in this region is carried out by Kosovo government at present. These three countries have been selected because of their different political and economic status that is important in the context of the dependence of the level of ecological light pollution from economic development (Bennie et al. 2015b) and proceeding from data availability. GIS layers showing the borders of strict protected areas for Serbia were computed via site Geosrbija (*https://a3.geosrbija.rs*) on the basis of Map of Protected areas of Serbia, available through *http://serbia.gdi.net/zzps/*. The data for strict protected areas of Bulgaria was uploaded from the website of the Executive Environment Agency, the Ministry of Environment and Water of the Republic of Bulgaria (*http://eea.government.bg/zpo/bg/index_download.jsp*). GIS layers with borders of Montenegrin National Parks were received by personal communication with these organizations; however, it is available schematically via *https://nparkovi.me/mapa-parkova/*

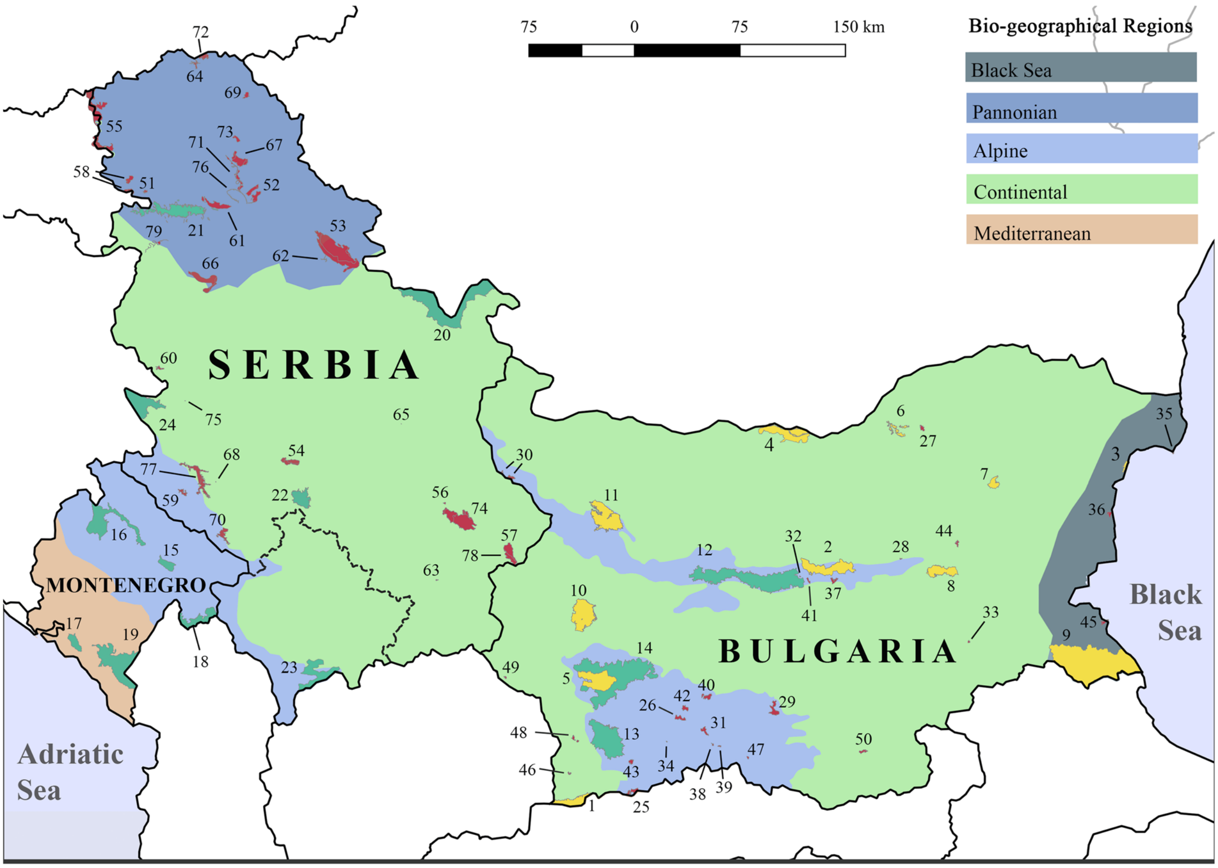
The objects of our study were 13 National Parks, 11 Nature Parks and 55 Reserves: 5 National Parks (Đerdap, Fruška Gora, Kopaonik, Šar Planina, Tara) and 29 Nature Reserves (Bagremara, Carska bara, Deliblatska peščara, Goč-Gvozdac, Gornje Podunavlje, Jelašnička klisura, Jerma, Karađorđevo, Klisura reke Mileševke, Klisura reke Trešnjice, Koviljsko-Petrovaradniski Rit, Kraljevac, Kukavica, Ludaško jezero, Mala jasenova glava, Obedska bara, Okanj bara, Paljevine, Pašnjaci velike droplje, Peštersko polje, Ritovi Donjeg Potisja, Selevenjske pustare, Slano Kopovo, Suva planina, Tesne jaruge, Titelski breg, Uvac, Venerina padina, Zasavica) in Serbia; 3 National Parks (Central Balkan, Pirin, Rila), 11 Nature Parks (Belasitsa, Bulgarka, Golden Sands, Persina, Rila Monastery, Rusenski Lom, Shumen Plateau, Sinite Kamani, Strandzha, Vitosha, Vrachanski Balkan), and 26 Nature Reserves (Ali Botush, Beglika, Beli Lom, Byala Krava, Chervanata Stena, Chuprene, Dupkata, Elenova Gora, Gorna Topchiya, Gornata Koria, Kaliakra, Kamenshchitza, Kastrakliy, Kamchia, Kazanite, Kupena, Leshnitsa, Mantaritza, Orelyak, Orlitzata, Ropotamo, Sokolata, Soskovcheto, Tisata, Tserna Reka, Velchi Dol) in Bulgaria; 5 National Parks (Biogradska gora, Durmitor, Lovćen, Prokletije, Skadarsko jezero) in Montenegro (Fig. 1). It is worth noting that there are 55 Nature Reserves in Bulgaria, but 29 of them are located within borders of National or Nature Parks, ; therefore, these territories have not been considered separately to avoid duplicating the results. Calculated data for these 29 areas are included in data for National and Nature Parks in a whole.

According to accepted biogeographic zoning (European Commission 2019; European Environment Agency 2012), they are located in the next way: 7 National Parks, 4 Nature Parks, and 15 Nature Reserves in Alpine region; 2 Nature Parks and 3 Nature Reserves in Black Sea region; 3 National Parks, 5 Nature Parks, and 21 Nature Reserves in Continental region; 2 National Parks in Mediterranean region; 1 National Park and 16 Nature Reserves in Pannonian region (Fig. 1).

The study has been carried out using available tools from Google Earth Pro (version 7.3.2.5776; https://www.google.com/earth/). We used the New World Atlas of Artificial Sky Brightness in the form of a kmz (Keyhole Markup language Zipped) layer which was created by Falchi et al. (2016) and is available through its 3D Globe version (https://cires.colorado.edu/Artificial-light). We overlaid the GIS layers of the borders of the protected areas with the artificial sky brightness layer and counted the number of squares of each index of level of artificial sky brightness according to the legend of the atlas (Falchi et al. 2016).

2 Results and Discussion

The results of area calculations of different levels of artificial sky brightness within protected territories are presented in Table 1 for Serbia, in Table 2 for Bulgaria, and in Table 3 for Montenegro. Total results for different types of protected areas of three countries have been summarized in Table 4, as well as total results for different biogeographic regions are given in Table 5. To quantify an error within the calculations, we have added two columns to each table, one column with the calculated area, and the other one with the official area (according to information from the Institute for Nature Conservation of Serbia (Brusin 2018), the Ministry of Environment and Water of Bulgaria (*https://www.moew.government.bg/bg/priroda/zastiteni-teritorii/obsta-informaciya-za-zastitenite-teritorii/*), and the Public Enterprise for National Parks of Montenegro (*http://nparkovi.me/dokumenti/*) for every protected area). The highlighted discrepancy is generally not more than 3–5% for studied territories in Bulgaria and Montenegro, except a few mountain ones like Rila Monastery Nature Park (7.83%). The common situation with results of ecological light pollution levels calculations for Serbian protected areas is the same, but there are several ones (Paljevine, Tesne jaruge, Jelašnička klisura and some others) with very small areas (less than 2.64 km^2), where the measurement errors are significantly higher because of rounding numbers, the possible inaccuracies in borders of protected areas, as well as the Google Earth measuring capabilities. Besides, calculated data for two nature reserves (Bagremara and Selevenjske pustare) is respectively 3.5 and 2.75 times bigger than official areas of these objects. That is connected with zoning of the territories. Official data include only areas of their strict protected zone, but the available GIS layer with borders of these protected areas does not contain information about zones. Therefore, we were not able to count the level of ecological light pollution only for strict protected zones there, and we have done it for whole territories of these nature reserves. Nevertheless, such big differentiation, in this case, does not have a significant impact on the total result, because total areas of Bagremara and Selevenjske pustare Nature Reserves are relatively small. In light of the above stated, the differentiation between total calculated area and total official area of all strict protected areas of the Republic of Serbia is 0.60%, for the Republic of Bulgaria, 0.86%



Nature Parks

Bulgaria

1 - Belasitsa
2 - Bulgarka
3 - Golden Sands
4 - Persina
5 - Rila Monastery
6 - Rusenski Lom
7 - Shumen Plateau
8 - Sinite Kamani
9 - Strandzha
10 - Vitosha
11 - Vrachanski Balkan

National Parks

Bulgaria

12 - Central Balkan
13 - Pirin;
14 - Rila

Montenegro

15 - Biogradska gora;
16 - Durmitor;
17 - Lovcen;
18 - Prokletije
19 - Skadarsko jezero

Serbia

20 - Đerdap
21 - Fruška Gora
22 - Kopaonik
23 - Šar Planina
24 - Tara

Nature Reserves

Bulgaria

25 - Ali Botush
26 - Beglika
27 - Beli Lom
28 - Byala Krava
29 - Chervanata Stena
30 - Chuprene
31 - Dupkata
32 - Elenova Gora
33 - Gorna Topchiya
34 - Gornata Koria
35 - Kaliakra
36 - Kamchia
37 - Kamenshchitza
38 - Kastrakliy
39 - Kazanite
40 - Kupena
41 - Leshnitsa
42 - Mantaritza
43 - Orelyak
44 - Orlitzata
45 - Ropotamo
46 - Sokolata
47 - Soskovcheto
48 - Tisata
49 - Tserna Reka
50 - Velchi Dol

Serbia

51 - Bagremara
52 - Carska Bara
53 - Deliblatska Peščara
54 - Goč-Gvozdac
55 - Gornje Podunavlje
56 - Jelašnička klisura
57 - Jerma
58 - Karađorđevo
59 - Klisura reke Mileševke
60 - Klisura reke Trešnjice
61 - Koviljsko-Petrovaradniski Rit
62 - Kraljevac
63 - Kukavica
64 - Ludaško jezero
65 - Mala jasenova glava
66 - Obedska bara
67 - Okanj bara
68 - Paljevine
69 - Pašnjaci velike droplje
70 - Pešstersko polje
71 - Ritovi Donjeg Potisja
72 - Selevenjske pustare
73 - Slano Kopovo
74 - Suva planina
75 - Tesne Jaruge
76 - Titelski breg
77 - Uvac
78 - Venerina padina
79 - Zasavica

Fig. 1 Studied strict protected areas in Bulgaria, Montenegro, and Serbia

Table 1 Areas with different levels of artificial sky brightness in the National Parks and Nature Reserves of Serbia

Protected area	Square of areas with different levels of artificial brightness (μcd/m^2), km^2								Calculated area, km^2	Official area, km^2
	> 6.96–13.9	> 13.9–27.8	> 27.8–55.7	> 55.7–111	> 111–223	> 223–445	> 445–890	> 890–1780		
Paljevine Nature Reserve		0.09							0.09	0.08
Tesne jaruge Nature Reserve				0.04					0.04	0.03
Jelašnička klisura Nature Reserve					1.19	0.05			1.24	1.16
Kukavica Nature Reserve			0.73						0.73	0.78
Mala jasenova glava Nature Reserve			0.07						0.07	0.06
Pašnjaci velike droplje Nature Reserve				10.08					10.08	9.79
Slano Kopovo Nature Reserve				8.40	1.30				9.70	9.76
Karađorđevo Nature Reserve				4.9	25.49				30.39	29.55
Bagremara Nature Reserve						2.93	0.90	0.32	4.15	1.18
Selevenjske pustare Nature Reserve					11.48	7.19			18.67	6.77
Ludaško jezero Nature Reserve						4.81	3.28	0.48	8.57	8.46
Gornje Podunavlje Nature Reserve			8.88	135.4	47.89	0.62	0.28	0.11	193.18	196.05
Koviljsko- Petrovaradinski Rit Nature Reserve					6.25	39.89	10.55	2.05	58.74	58.95
Okanj bara Nature Reserve				6.23	43.77	5.91	0.64		56.55	54.81
Carska bara Nature Reserve					42.33	4.73			47.06	47.26
Titelski breg Nature Reserve					4.79	0.16			4.95	4.96
Ritovi Donjeg Potisja Nature Reserve				4.66	25.5				30.16	30.11
Zasavica Nature Reserve					3.25	2.80	0.10	0.07	6.22	6.71
Obedska bara Nature Reserve					83.99	14.70			98.69	98.20
Klisura reke Trešnjice Nature Reserve			6.29						6.29	5.95
Deliblatska peščara Nature Reserve				215.05	132.91	4.34			352.30	348.29
Kraljevac Nature Reserve					1.51	0.85			2.36	2.64
Suva planina Nature Reserve			123.51	52.39	5.48				181.38	181.17
Jerma Nature Reserve		25.31	44.13						69.44	69.94
Venerina padina Nature Reserve		0.003							0.003	0.003
Peštersko polje Nature Reserve		31.10							31.10	31.18
Klisura reke Mileševke Nature Reserve		7.16	5.17						12.33	12.44
Goč-Gvozdac Nature Reserve			13.91	25.52					39.43	39.57
Uvac Nature Reserve		32.69	38.62	6.06					77.37	75.43
Šar planina National Park				226.96	0.77				227.73	228.05

Table 1 (continued)

Protected area	Square of areas with different levels of artificial brightness (μcd/m²), km²								Calculated area, km²	Official area, km²
	> 6.96–13.9	> 13.9–27.8	> 27.8–55.7	> 55.7–111	> 111–223	> 223–445	> 445–890	> 890–1780		
Kopaonik National Park			51.27	66.37	2.97				120.61	119.69
Tara National Park		130.09	77.32	40.93					248.34	249.92
Đerdap National Park	52.62	364.33	119.75	64.47	19.81	10.11	4.63	0.78	636.5	637.86
Fruška gora National Park					130.20	98.30	37.53	0.12	266.15	266.72
	52.62	590.77	489.65	867.47	590.88	197.39	57.91	3.93	2850.61	2833.52
	1.85%	20.72%	17.18%	30.43%	20.73%	6.92%	2.03%	0.14%	100%	

and for Montenegro, 0.20%. If it is considered for different types of protected areas, then the differentiation between total calculated area and total official area for National Parks is 0.01%, for Nature Parks, 0.25%, and for Nature Reserves, 0.27%. The similar situation is in biogeographic regions: Alpine region, 1.15%; Black Sea region, 0.83%; Continental region, 0.74%; Mediterranean region, 0.12%; Pannonian region, 1.50%.

According to Falchi et al. (2016), a night sky can be considered "pristine", if its level of artificial brightness is no more than 1% or < 1.74 μcd/m². There are no such areas as in studied countries and as within the Balkans as a whole that we can set from the 3D Globe version of the New World Atlas of Artificial Sky Brightness even visually. This fact alone allows saying about the wide-spread incursion of ALAN within strict protected areas in all Balkan countries. However, let us consider it below on separated examples using obtained data (Tables 1, 2, 3, 4, 5, Figs. 2, 3).

As seen from Tables 1, 2, and 3, the lowest level of artificial sky brightness for strict protected areas of Serbia, Bulgaria, and Montenegro is > 6.96–13.9 μcd/m². There are 1.85% from the total area of national parks and nature reserves in Serbia with such level of ALAN, 18.83% from the total area of nature reserves, national and nature parks in Bulgaria, and 22.64% from the total area of Montenegrin National Parks. The cleanest protected areas in the context of ALAN pollution are Strandzha Nature Park, Nature Reserves "Dupkata," "Beglika," "Gornata Koria," and "Kazanite" in Bulgaria, as well as National Park "Durmitor" in Montenegro. Besides, Đerdap National Park in Serbia has a plot with a low level of light pollution; however, there are also strong polluted ones at the same time. It is the last level when a night sky can be considered relatively clean, because a night sky with artificial brightness in > 13.9–27.8 μcd/m² is polluted on an astronomical point of view (Falchi et al. 2016). There are 1200.64 km² or 13.74% of strict protected areas of Serbia, Bulgaria, and Montenegro (Table 4, Fig. 2) with artificial sky brightness in > 6.96–13.9 μcd/m². On one hand, it is a small part of total territory, but, on the other hand, that is a unique situation for Continental Europe if Eastern Europe (Peregrym et al. 2018, 2019) and the Scandinavian Peninsula are not taken into account, because the similar territories are practically absent there (Bennie et al. 2015a, b, c; Bennie et al. 2015b, c; Falchi et al. 2016, 2019; Gaston et al. 2015a).

Table 2 Areas with different levels of artificial sky brightness in the Nature Reserves, National, and Nature Parks of Bulgaria

Protected area	Square of areas with different levels of artificial brightness (μcd/m²), km²								Calculated area, km²	Official area, km²
	> 6.96–13.9	> 13.9–27.8	> 27.8–55.7	> 55.7–111	> 111–223	> 223–445	> 445–890	> 890–1780		
Central Balkan National Park		495.51	192.20	27.30	0.43				715.44	720.21
Pirin National Park		289.49	85.07	32.96	0.55				408.07	403.56
Rila National Park		594.86	174.99	8.35					778.2	810.46
Belasitsa Nature Park			45.31	56.40	14.77	0.62			117.1	117.32
Bulgarka Nature Park		3.71	156.81	78.67					239.19	217.72
Golden Sands Nature Park					5.46	2.67	5.09		13.22	13.25
Persina Nature Park			47.17	97.61	72.75	6.12			223.65	217.62
Rila Monastery Nature Park		227.51	24.67						252.18	273.71
Rusenski Lom Nature Park			31.35	4.00					35.35	34.08
Sinite Kamani Nature Park			27.80	46.06	34.18	10.20	3.49		121.73	113.81
Shumen Plateau Nature Park				11.09	14.54	12.32	1.39		39.34	39.31
Strandzha Nature Park	897.81	228.51	23.92	1.93					1152.17	1160.54
Vitosha Nature Park				29.35	110.78	77.69	40.91	11.50	270.23	270.78
Vrachanski Balkan Nature Park		0.78	213.05	52.13	20.05	2.26	0.01		288.28	301.30
Kaliakra Nature Reserve		7.14							7.14	8.66
Tisata Nature Reserve			5.30	0.52					5.82	5.84
Dupkata Nature Reserve	10.98	1.05							12.03	12.11
Kamchia Nature Reserve				8.47					8.47	8.50
Gorna Topchiya Nature Reserve		1.64							1.64	1.64
Ali Botush Nature Reserve		16.40							16.40	16.48
Soskovcheto Nature Reserve			1.38	0.45					1.83	1.78
Beglika Nature Reserve	2.73	11.86							14.59	14.61
Elenova Gora Nature Reserve		0.22	0.32						0.54	0.54
Kupena Nature Reserve			6.14	9.93	0.33				16.40	17.61
Chervanata Stena Nature Reserve			21.75	8.65					30.40	30.29
Mantaritza Nature Reserve		10.87							10.87	10.69
Gornata Koria Nature Reserve	1.61								1.61	1.61
Byala Krava Nature Reserve		0.93							0.93	0.93
Kastrakliy Nature Reserve		1.29							1.29	1.29
Kazanite Nature Reserve	1.55								1.55	1.55

Table 2 (continued)

Protected area	Square of areas with different levels of artificial brightness (μcd/m^2), km^2								Calculated area, km^2	Official area, km^2
	> 6.96–13.9	> 13.9–27.8	> 27.8–55.7	> 55.7–111	> 111–223	> 223–445	> 445–890	> 890–1780		
Chuprene Nature Reserve		14.49							14.49	14.52
Beli Lom Nature Reserve			7.74						7.74	7.76
Tserna Reka Nature Reserve		1.96							1.96	1.96
Velchi Dol Nature Reserve		7.74							7.74	7.76
Orlitzata Nature Reserve		5.66							5.66	5.67
Kamenshchitza Nature Reserve			5.29	4.86					10.15	10.17
Leshnitsa Nature Reserve			3.21	0.67					3.88	3.89
Orelyak Nature Reserve		6.14	1.42						7.56	7.57
Sokolata Nature Reserve		0.20	2.01						2.21	2.20
Ropotamo Nature Reserve			9.98	0.01					9.99	10.01
	914.68	1927.96	1086.88	479.41	273.84	111.88	50.89	11.5	4857.04	4899.31
	18.83%	39.69%	22.38%	9.87%	5.64%	2.30%	1.05%	0.24%	100%	

Table 3 Areas with different levels of artificial sky brightness in the National Parks of Montenegro

Protected area	Square of areas with different levels of artificial brightness (μcd/m^2), km^2							Calculated area, km^2	Official area, km^2
	> 6.96–13.9	> 13.9–27.8	> 27.8–55.7	> 55.7–111	> 111–223	> 223–445	> 445–890		
Biogradska gora		50.88	8.20	0.20				59.28	56.50
Durmitor	233.34	80.91	6.75	3.46				324.46	325.19
Lovćen					61.75			61.75	62.20
Prokletije		155.58	5.31	0.08				160.97	160.38
Skadarsko jezero				281.63	121.89	19.21	1.42	424.15	424.27
	233.34 22.64%	287.37 27.88%	20.26 1.97%	285.37 27.69%	183.64 17.82%	19.21 1.86%	1.42 0.14%	1030.61 100%	1028.54

Table 4 Total results of area calculation of different levels of artificial sky brightness for strict protected territories of Serbia, Bulgaria, and Montenegro

Protected area		Square of areas with different levels of artificial brightness (μcd/m²)								Calculated area, km²	Official area, km²
		> 6.96–13.9	> 13.9–27.8	> 27.8–55.7	> 55.7–111	> 111–223	> 223–445	> 445–890	> 890–1780		
National parks	km²	285.96	2161.65	720.86	752.71	338.37	127.62	43.58	0.9	4431.65	4465.01
	%	6.45	48.78	16.27	16.98	7.64	2.88	0.98	0.02	100	
Nature parks	km²	897.81	460.51	570.08	377.24	272.53	111.88	50.89	11.5	2752.44	2759.44
	%	32.62	16.73	20.71	13.71	9.90	4.06	1.85	0.42	100	
Nature reserves	km²	16.87	183.94	305.85	502.29	437.46	88.98	15.75	3.03	1554.17	1536.92
	%	1.08	11.84	19.68	32.32	28.15	5.73	1.01	0.19	100	
Total	km²	1200.64	2806.1	1596.79	1632.24	1048.36	328.48	110.22	15.43	8738.26	8761.37
	%	13.74	32.11	18.27	18.68	12.00	3.76	1.26	0.18	100	

Nevertheless, strict protected areas of Serbia and Montenegro are very strongly polluted by ALAN generally (Fig. 2). So, there are 60.25% of strict protected areas of Serbia with artificial sky brightness more than 55.7 μcd/m² and the maximum value of 1780 μcd/m². It is 47.51% for Montenegro, but with the maximum value of 890 μcd/m². The current situation in Bulgaria is different. There are only 19.1% of Bulgarian strict protected areas with artificial sky brightness more than 55.7 μcd/m² and the maximum value of 1780 μcd/m². Moreover, though there is almost 40% which are polluted on an astronomical point of view, potentially these can be cleared using a right policy in combating among ecological light pollution (Dick 2014, 2018; Hölker et al. 2010a).

Considering a potential "cleaning up" in strict protected areas from ALAN separately except Bulgarian National Parks, Rila Monestry Nature Park, and some Nature Reserves, the most perspective territories are National Parks "Prokletije" and "Biogradska gora" in Montenegro, as well as Tara National Park in Serbia. That is because they are located far enough from big settlements with developed infrastructure. Unfortunately, at present, it is complicated to wait for significant success in decreasing of ecological light pollution in National Parks like "Lovćen" and "Skadarsko jezero" because they are surrounded by cities and villages oriented to touristic business with active night life.

The result of data analysis from Table 4 shows that as a percentage the most ALAN polluted one are Nature Reserves among different types of strict protected areas of Serbia, Bulgaria, and Montenegro. There are 67.4% of them with artificial sky brightness more than 55.7 μcd/m² and the maximum value to 1780 μcd/m². At the same time, it is 28.5% and 29.94% for national and nature parks, respectively. However, based on areas, the most polluted territories are national parks because there are 1268.18 km² of their total area with artificial sky brightness more than 55.7 μcd/m² and the maximum value to 1780 μcd/m². This indicator is not significantly lower for nature reserves and nature parks—1047.51 km² and 824.04 km², respectively.

As seen from Table 5 and Fig. 3, the representation of Serbian, Bulgarian, and Montenegrin strict protected areas in biogeographic regions is different; therefore, it is not correct to compare them. However, it is clear that the most polluted strict protected areas by ALAN are located in the Mediterranean and Pannonian regions. Here is the lowest level in > 27.8–55.7 μcd/m² for

Table 5 Total results of area calculation of different levels of artificial sky brightness for strict protected territories according to biogeographic regions within Serbia, Bulgaria, and Montenegro

Biogeographic region		Square of areas with different levels of artificial brightness (μcd/m^2)								Calculated area, km^2	Official area, km^2
		> 6.96–13.9	> 13.9–27.8	> 27.8–55.7	> 55.7–111	> 111–223	> 223–445	> 445–890	> 890–1780		
Black Sea	km^2	897.81	235.65	33.9	10.41	5.46	2.67	5.09		1190.99	1200.96
	%	75.38	19.79	2.85	0.87	0.46	0.22	0.43		100	
Continental	km^2	52.62	608.90	647.45	471.46	165.69	39.42	9.51	0.78	1995.83	1981.16
	%	2.64	30.51	32.44	23.62	8.30	1.98	0.47	0.04	100	
Pannonian	km^2			8.88	384.72	560.66	187.23	53.28	3.15	1197.92	1180.21
	%			0.74	32.12	46.80	15.63	4.45	0.26	100	
Alpine	km^2	250.21	1961.55	906.56	484.02	132.91	79.95	40.92	11.5	3867.62	3912.57
	%	6.47	50.71	23.44	12.51	3.44	2.07	1.06	0.30	100	
Mediterranean	km^2				281.63	183.64	19.21	1.42		485.90	486.47
	%				57.96	37.79	3.96	0.29		100	
Total	km^2	1200.64	2806.10	1596.79	1632.24	1048.36	328.48	110.22	15.43	8738.26	8761.37
	%	13.74	32.11	18.27	18.68	12.00	3.76	1.26	0.18	100	

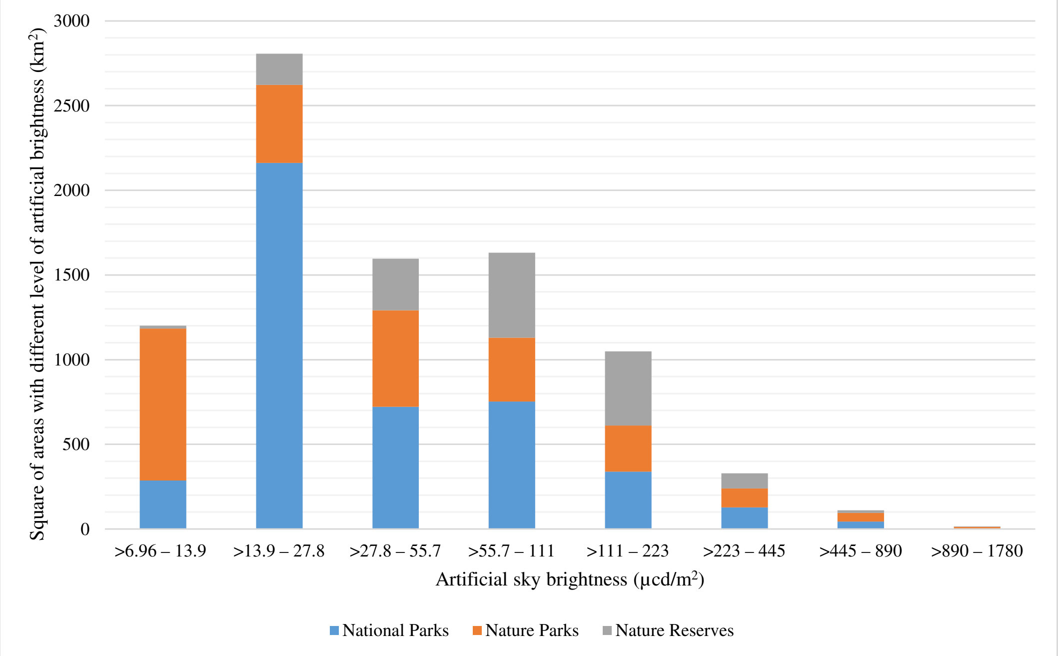


Fig. 2 Distribution of strict protected area types in respect to different levels of artificial sky brightness in Serbia, Bulgaria, and Montenegro

Pannonian region and in > 55.7–111 µcd/m^2 for Mediterranean one. It is easy to explain because all seashore regions are strongly polluted by ALAN due to their attraction for tourists and transport infrastructure (Bennie et al. 2015c). Pannonian region within Serbia has a large number of population as well as some industry districts which provide the high level of ecological light pollution there. It was logical to expect the similar data for Black Sea region and the Mediterranean region which are quite popular among tourists. However, within Strandzha Nature Park, which is the biggest strict protected area and the cleanest one from ALAN in the region, there is the lowest level of ecological light pollution among all biogeographic regions represented in studied countries of the Balkans. It is a very positive moment because Strandzha is a unique place which considered to be a refugia of thermophilic plant species in the last glacial time (Patronov 2005). Also a relatively low level of ecological light pollution is in Alpine region that is connected with poorly developed infrastructure in high mountains. Nevertheless, there is 50.71% of strict protected areas polluted by ALAN on an astronomical point of view, and 42.82% has higher level of this pollution. The current situation is significantly worse in Continental region. Here is only 2.64% of strict protected areas which are relatively clean, with artificial brightness in range > 6.96–13.9 µcd/m^2. Though there is a big potential for decreasing the level of ecological light pollution in this region, since 30.51% or 608.90 km^2 has artificial brightness in range > 13.9–27.8 µcd/m^2.

3 Conclusions

Thus, there is no doubt that ALAN significantly influences biota and its habitats in the Balkans, including strict protected areas. It is a new threat for nature conservation not just in Northern Serbia as mentioned earlier (Bjelajac and Đerčan 2019), but in the whole region. At least, this is confirmed by our results of the investigation for Serbia, Bulgaria, and Montenegro. The current research shows only a static situation for strict protected areas of Balkan countries because the New World Atlas of Artificial Sky Brightness (Falchi et al. 2016) does not allow making any dynamical estimation. However, taking into account the pace of ecological light pollution in the world increasing by a degree of ~ 2% per year (Kyba et al. 2017), and the uniqueness of the Balkan Peninsula, first of all, it is very important to save dark skies in this region wherever possible, as well as to start combating for decreasing of ecological light

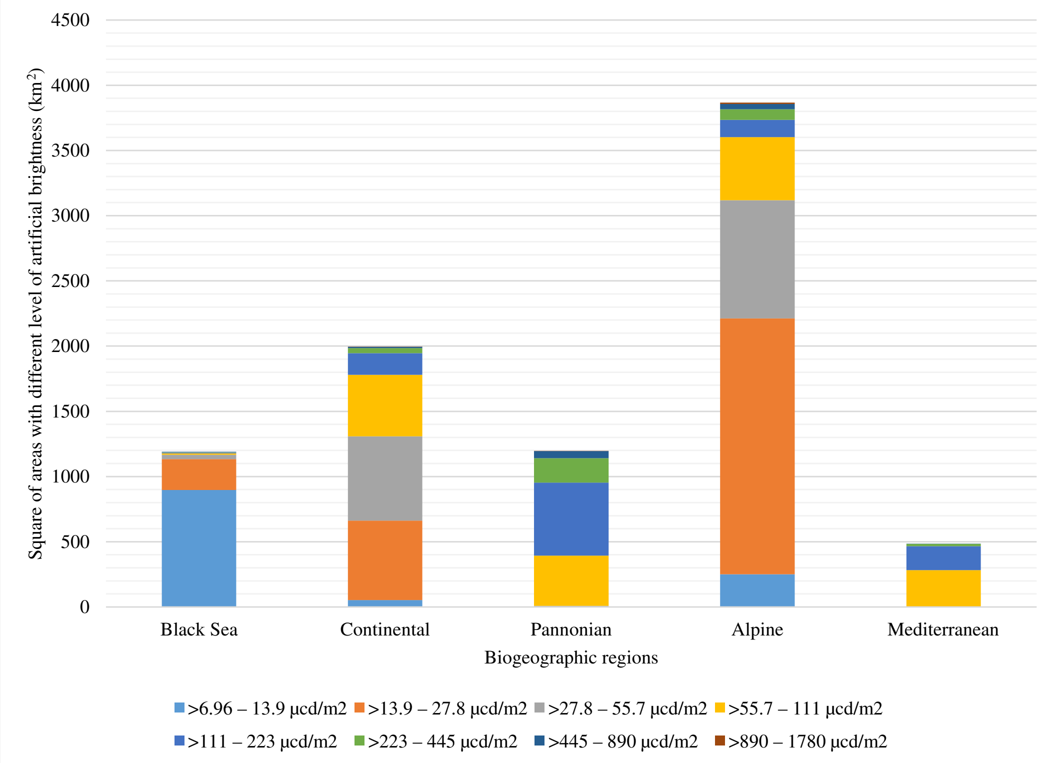


Fig. 3 Distribution of territories with different levels of artificial sky brightness in respect to biogeographical regions within Serbian, Bulgarian, and Montenegrin strict protected areas

pollution level where it is more perspective. Such activity has to be carried out within strict protected areas firstly, and has to be directed to both practical and educational aims. More difficult goal is to expand dark territories around these strict protected areas. Certainly this will be very hard to realize because of fast infrastructure development in these countries which is apparently often accompanied by increasing area of polluted territories, as well as the level of light pollution. However, the ideal aim is to build a regional network of dark areas which will join territories without light pollution or with its minimal level. It is needed for removal of any biogeographical barriers which appeared due to development of settlement light systems, since they influence on gene drift in populations significantly (Hopkins et al. 2018).

We think that changes in approaches to street light and lighting of buildings within protected areas and their surroundings, according to accepted recommendations (Dick 2014, 2018; Kolláth et al. 2016), have to be among the first practical steps. The next stage is creation of special buffer zones around strict protected areas for decreasing the ALAN impact from light sources of settlements and their infrastructure as well as starting taking into account ALAN effects during development of conservation management plans for protected areas and creation of new ones.

However, these actions must be simultaneous with designing and implementation of educational strategies, because nowadays even scientific popular information about the ALAN problem are limited. Also, it is very important to show to local communities the benefits from saving the dark sky and its impact on well-being, and as a result, conservation activities should be more effective. It is possible to do it by international collaboration, as an example in the framework of the International Dark Sky Places conservation program (*http://darksky.org/idsp/*) which has been initiated by the International Dark-Sky Association since 2001 (Barentine 2016). Fulfilling the requirements for

International Dark Sky Places should provide benefits for both biodiversity conservation and tourism within protected areas. Such a positive experience has been documented in many countries, for example, in adjacent Hungary (Gyarmathy and Kolláth 2017).

Finally, continuous gathering of scientific facts about mechanisms of ALAN influence on biodiversity and protected areas is very important. Balkan countries could be a profitable place for it because of their unique biodiversity and habitat richness on a relatively small area.

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