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LIGHT POLLUTION OF THE MOUNTAIN AREAS IN POLAND

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Abstract: The existence of extensive records for the impact of night sky brightness on the animals' behavior in their natural environment shows the need to investigate the level of artificially induced night sky glow (light pollution) in the protected areas.

The results of multi-night sky brightness measurements carried out at the selected sites in Polish mountain areas under various atmospheric conditions are presented. Conducted measurements show a strong impact of the artificial sky glow on the night sky brightness, which is the essence of light pollution. The influence of both distant urban centers, as well as local tourist resorts on the size of studied phenomenon in the mountain areas, which causes both ecological and touristic degradation of these areas was stated. In a few studied areas the level of night sky brightness greatly exceeds the natural one and is comparable to such levels measured inside the cities. It was found that only the southern part of the Polish Carpathians can be considered an area free of light pollution.

INTRODUCTION

Artificial sky glow is only one of several types of light pollution. It consists in the glow of the night sky due to the scattering of ground artificial light in the atmosphere. This is not a dominant component of light pollution, however, it strongly affects the surroundings of cities, which are the sources of light pollution, even in the case when these areas are protected from other, direct components of light pollution [14, 15]. This type of light pollution is visible even from afar as the glow of light in the sky.

The influence of light on living organisms has long been the subject of research. As early as in the nineteenth century the impact of light houses and lighted ships on mortality of the night-migratory birds was described [1]. In 1917, the Californian ornithologist Carlos Lastreto noted the rerouting of night flights of the migratory birds under the influence of light of the lighthouses [22]. At the end of the nineteenth century the massive losses among the insects, the songbirds' food, have been also highlighted and associated with the urban street lighting in the United Kingdom [6]. In the 1950s the Dutch ecologist F.J. Verheijen reviewed the European and Japanese literature on the effects of light on the animals [26]. In the 1970s zoologists drew attention to the disturbances of biological clocks and changes in the behavior of nocturnal animals, associated with the growth of artificial illumination. In this period the term "light pollution" was introduced in astronomy and began to be treated as an equivalent to other types of pollution [7]. Also, at the same time Verheijen introduced the term "photo pollution" in biological sciences [27].

This kind of light pollution is interesting mostly for astronomers largely because it interferes with visual observations both in the cities as well as their surroundings. However, also a significant effect of an artificial night sky glow on local ecosystems is evident [20]. The wide spread use of lighting in the streets and squares even in small towns, especially tourist ones, is the cause of the occurrence of this effect not only in the vicinity of major urban centers but also in other areas of dense population. This is a problem even for astronomical observatories or nature reserves located in remote areas.

The problem of light pollution began to grow rapidly in Poland in the end of the 1990s [23]. At the same time it was possible to map the emission of light from the surface of the Earth on the base of available satellite data [4]. It became also possible to create the maps of the predicted night sky brightness based on a model using the visual observations of the faintest stars visible by the naked eye [5].

At the same time another astronomical method for assessing the surface brightness of the sky, using the faint comets observations, was developed in Poland. Its results published initially in 2005 [23] and comprehensively in 2010 [24] are in broad agreement with the model of the night sky brightness developed on the basis of the faint stars visibility [4, 5].

Both of the above mentioned astronomical methods are indirect although well verified. The appearance on the market of simple, small, and also cheap meters of the sky brightness (Sky Quality Meter, SQM) produced by Unihedron company allowed to conduct direct measurements anywhere in the field not only in the case of a cloudless sky, but also in any atmospheric conditions [24].

USED UNITS

The surface brightness of the night sky, denoted as S_a, measured by the SQM is given in the commonly used astronomical units of magnitudes per square arc second (mag/arcsec^2). It is a derivative of the magnitude scale (mag, magnitude, ^{m}) defining the visual impact of the star's brightness as a point light source. Magnitude scale is a logarithmic, relative and reverse one, in which a star of magnitude 0 is 100 times brighter than a star of magnitude 5. The mag/arcsec^2 scale determines the surface brightness of diffuse astronomical objects such as nebulae, galaxies, comets, or just a background sky. The unit of surface brightness in the SI system is candela per square meter (cd/m^2). The relationship between these quantities is described by the following formula:

$$[\text{cd/m}^2] = 10.8 \cdot 10^4 \cdot 10\text{\^{}}(-0.4 \cdot [\text{mag/arcsec}^2]) \quad (1)$$

Because of the very low brightness of the night sky the commonly used unit is milicandela per square meter (mcd/m^2). Due to the reference to other publications regarding this problem as well as readings from SQMs, we use mainly the scale [mag/arcsec^2], giving also the appropriate values in the scale [mcd/m^2].

RESULTS OF THE MEASUREMENTS

In order to examine the level of light pollution in the vicinity of protected areas, such as national parks and reserves, we carried out, using the SQMs, a series of the S_a measurements for several mountain locations in Poland (see Table 1). Especially interesting is the position SUH located on the mountaintop within the Gorce National Park but these measurements are still in progress and we do not use them in this study. Also, we made the measurements in the vicinity of the cities of Dobczyce (Island Beskids) and of Żywiec (Żywiec Beskids). In the case of position KUD the observations of comets conducted from 1994 allowed us also to determine the changes in the value of S_a for the cloudless sky in a few years.

Table 1. List of the measuring places

Code	Locality	Geographical region	Latitude/longitude/ elevation	Number of measurements/season
BOL	Bolechowice	Kraków-Częstochowa Upland	50º08'49"N 19º47'33"E 273 m	83 all the year
JAW	Jaworze Górne	Silesian Beskids	49º47'43"N 18º55'39"E 373 m	35 all the year
JER	Jerzmanowice	Kraków-Częstochowa Upland	50º12'43"N 19º45'01"E 448 m	169 all the year
KAS	Kasinka Mała	Island Beskids	49º41'32"N 20º02'16"E 399 m	17 summer, autumn
KUD	Kudłacze	Maków Beskids	49º46'51"N 20º01'12"E 698 m	20 summer, winter
MOG	Mogilany	Wieliczka Piedmont	49º56'21"N 19º54'24"E 333 m	333 all the year
PRZ	Przesieka	Giant Mountains/ Karkonosze	50º48'44"N 15º40'20"E 493 m	15 summer
ROZ	Roztoki Górne	Bieszczady Mountains	49º09'13"N 22º19'03"E 698 m	17 summer, winter
SUH	Mount Suhora Astronomical Observatory	Gorce Mountains	49º34'10"N 20º04'02"E 985 m	measurements in progress
ZAK	Zakopane	Tatra Mountains	49º19'15"N 19º56'40"E 1013 m	22 summer, winter

An analysis of the literature [2, 19, 25] shows that the value of S_a corresponding to the darkest cloudless night sky on Earth is equal to 21.6–21.9 mag/arcsec^2, which corresponds to the night sky surface brightness 0.19–0.25 mcd/m^2. Our measurements showed a similar value only for the position ROZ (S_a=21.5 mag/arcsec^2 = 0.27 mcd/m^2), which can thus be regarded as one of the least light polluted sites in Poland. This is consistent with the existing model map for light pollution [5].

We believe that basing on the measured maximum values of S_a for a cloudless sky (i.e. the smallest brightness of the sky background) four classes of light polluted upland areas can be distinguished, linked to both the local population density as well as to the location of the test site in relation to the major urban centers: I – the interiors of the mountains, located several kilometers from the nearest urban centers (ROZ, S_a> 21.5 mag/arcsec^2 = 0.27 mcd/m^2); II – the borders of the mountains, located up to several kilometers from the smaller urban centers (KUD, KAS, KAR, JAW, S_a = 20.5–21.5 mag/arcsec^2 = 0.27–0.68 mcd/m^2); III – the foothills and the mountains, located up to a dozen or so kilometers from major urban centers (MOG, BOL, JER, S_a = 19.5–20.5 mag/arcsec^2 = 0.68–1.71 mcd/m^2); IV – the foothills and the mountains surrounding the large urban centers (Bielsko-Biala and Wałbrzych, during tests, S_a<19.5 mag/arcsec^2 = 1.71 mcd/m^2). Zakopane (ZAK) due to its strong urbanization should be classified in the transition class between II and III. It can be noticed that depending on the location within the mountain areas in Poland the brightness of a cloudless night sky changes in the range from 19.5 to 21.5 mag/arcsec^2, which corresponds to the changes of sky surface brightness in the range from 0.27 to 1.71 mcd/m^2. This means more than sixfold increase in brightness of the cloudless night sky within some parts of the Polish mountain areas comparing to such areas free of light pollution.

Based on the above data we concluded that the key to the level of the artificial sky glow is the distance of researched area from a nearby locality, which is the source of light pollution. Therefore, we introduced a distinction between the “distant light pollution”, the sources of which are distant urban centers, and the “local light pollution”, whose source is the local lighting dissipated by the near-surface atmospheric factors, such as fog or particulate matter (PM). In the surveyed positions the local light pollution in the absence of such distractions seems to be of secondary importance.

THE TIME CHANGES OF LIGHT POLLUTION

In the region of position KUD observations and measurements done for the period 1994–2010, allowed us to notice the time changes in the value of S_a in the Maków Beskids (Fig. 1).

Back in 1995 the cloudless night sky in this area was darker than currently observed in the Bieszczady Mountains – the value of S_a was equal to 22.5 mag/arcsec^2 (0.11 mcd/m^2). Starting this year the S_a value increased to reach 20.7 mag/arcsec^2 (0.57 mcd/m^2) in 2004. It means over fivefold increase in the surface brightness of a cloudless night sky in this case.

This effect could be associated both with the increase of lighting in the vicinity of the research position in this period (especially generated by the cities of Myślenice and Pcim), as well as approaching the border of the light-island of Cracow, 30 km away [16].

We have not detected any increase of light pollution in this area in subsequent years.

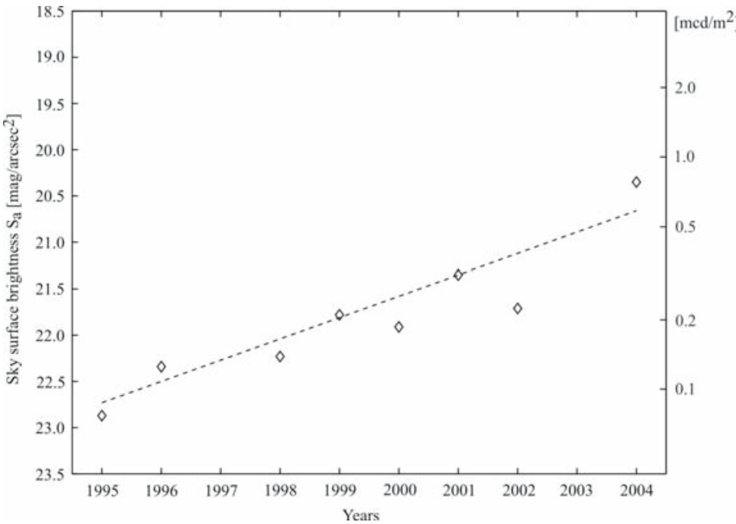

Fig.1. The surface brightness of the night sky in 1995-2004 in the region of position KUD in the Maków Beskids.

INFLUENCE OF METEOROLOGICAL CONDITIONS ON THE LEVEL OF LIGHT POLLUTION

Using Sky Quality Meters (SQMs) we examined the dependencies of S_a on a number of parameters determining the state of the atmosphere in the measurement positions during 2009. We found that the greatest impact on the brightness of the night sky have clouds, haze and (in the case of a cloudless sky) particulate matter [10].

Cloudiness

We found that the night sky brightness is proportional to the magnitude of cloud cover. For all research positions we have stated the probably linear dependencies of S_a values on the cloudiness (Fig. 2).

In the case of five research positions the measured values of S_a were decreasing by an amount equal to about 1.5 mag/arcsec^2 along with cloud cover increasing in the range from 0% to100%, which means a fourfold increase in the surface brightness of the sky. This means that the clouds reflecting artificial lighting from the ground significantly increase the surface brightness of the night sky. Interestingly, the magnitude of change of the S_a value is independent of the measurement's position. Ranging from the cloudless sky to overcast it is equal to 1.5 mag/arcsec^2, irrespective of whether the measurement's position is the center of a large city (Cracow, Lublin), outskirts of a big city's light-island (the MOG position) or even the mountain area far from the city (KUD position, about 30 km south of Cracow, or PRZ, around 11 km south of Jelenia Góra). Only in the southern part of the Polish Carpathian Mountains (ROZ position, 7 km south of Cisna) we found the decrease of the night sky brightness with the increase of cloudiness, what is typical for the Class I of the night sky quality.

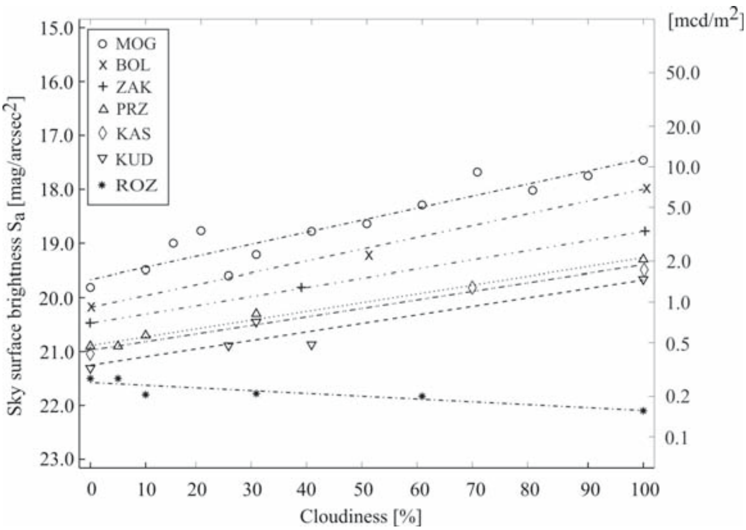

Fig. 2. The S_a value vs. the estimated magnitude of cloudiness (S_a values were averaged for the subsequent percentages of cloud cover) (MOG – Mogilany, 14 km south of the Cracow center, BOL – Bolechowice, 14 km north-west of Cracow, ZAK – Zakopane, PRZ – Przesieka, 11 km south of Jelenia Góra, KAS – Kasinka Mała, 15 km south of Myślenice, KUD – Kudłacze hamlet, 30 km south of the Cracow center, ROZ – Roztoki Górne, 7 km south of Cisna)

For the four defined earlier classes of the light polluted areas, the brightness of the completely overcast sky is equal to: Class I –S_a >22 mag/arcsec² (< 0.17 mcd/m²), Class II – S_a = 19–20 mag/arcsec² (1.08–2.71 mcd/m²), Class III – S_a = 17.5–18.5 mag/arcsec² (4.30–10.8 mcd/m²), Class IV – S_a<17.5 mag/arcsec² (> 10.8 mcd/m²) .

Of course, the size of the effect of the artificial ground lighting reflected by the clouds on the ground illumination, considered by us to be the main component of a distant light pollution, depends both on the population of a city, which is the source of light illuminating the clouds [24], as well as the distance of the measurement's position from it, and probably also on the reflective ability (albedo) or the type of clouds, but this issue requires further investigation. So far, we have noticed that low snow clouds have the greatest reflective ability and high cirrus clouds have the least one.

The above data indicate that among the positions where we made our measurements, only the one located in the Bieszczady Mountains is free from the distant light pollution, which is important in terms of potential impact on local ecosystems. For other mountain positions (Class II, III and IV) an overcast sky is at least four times brighter than the cloudless sky.

Haze

For several positions (MOG, PRZ, ZAK, ROZ) we have researched the effect of fog on the light pollution level. We found a dependence of the S_a value on the haze magnitude and noticed that it is very similar to such dependence on the cloudiness. For MOG and ZAK positions we stated the decrease of S_a in the foggy nights as much as

2 mag/arcsec^2 what means over sixfold increase in the brightness of the sky. In the Bieszczady Mountains (ROZ position) the surface brightness of the sky decreases with an increase of haze. We have also stated a similar decrease in the brightness of the night sky with an increase of haze for the position PRZ in the Giant Mountains/Karkonosze, although (as mentioned earlier) this position is liable to the distant light pollution stemming from nearby Jelenia Góra and with the lack of fog the sky brightness at this position increases with the increasing cloudiness. Observed effect can be associated both with a small amount and a small brightness of local artificial light sources, which light is scattered by the particles of the mist on the test position, as well as to the isolation effect of the upper layers of mist on distant light pollution. We found a similar isolation effect at the MOG position, where the presence of fog at the downstream Cracow causes a significant reduction of the associated distant light pollution. At the ROZ position both a lack of any local light sources and the isolation of natural light of stars by the haze are the reason of the extreme form of described effect, therefore the measured values of S_a are very high, resulting in almost total darkness.

This type of light pollution consisting of the above described local illumination scattered by the atmospheric aerosols was included into the pre-defined local light pollution.

Particulate matter

In the analysis of the measurement data we made the hypothesis that at the absence of fog and with the cloudless sky one of the main factors diffusing light, coming from the ground sources, can be the particulate matter (PM) suspended in the atmosphere. To test this hypothesis we used the PM10 values measured at several monitoring stations in Cracow and the surrounding area averaged over successive months of 2009 and published in subsequent issues of the WIOŚ Bulletin [3].

We found that the annual changes of the S_a value have similar characteristic as the annual changes of PM10 values – the largest concentration of suspended particles, like the brightness of the night sky, is recorded in the winter months, while the lowest in the summer months. We proposed the close relationship between the S_a and PM10 values for the cloudless sky. Obtained dependencies of S_a vs. PM10 are linear regardless of whether the measurement was done at the center of a big city (Cracow) or at the Wieliczka Piedmont in Mogilany (position MOG). With the increase of the PM10 value the value of S_a is reduced by over 1 mag/arcsec^2, which means almost threefold increase in the surface brightness of the night, cloudless sky [24].

We believe that the scattering of light by the particulate matter, in the case of its high concentration, is the dominant factor of light pollution in the villages located in mountainous areas far from major urban centers, for which the distant light pollution is minimal (the class II of the night sky quality). In this case, the source of light pollution is the light generated by a local ground light sources, scattered by the particulate matter derived from a low-emission sources. This effect is especially pronounced in winter. Scattering of light by the particles of particulate matter in that case should be classified as the local light pollution. But unlike the scattering by the particles of fog, in this case the isolation of light coming from the upper atmosphere (e.g. reflected from the clouds) seems to be much smaller, thus the distant light pollution is reduced to a much lesser extent. It seems that the particulate matter from the low-emission sources (especially in winter) may be one of the main causes of light pollution in such mountain resorts as Krynica, Karpacz and Szklarska Poręba, but this problem needs further study.

EFFECT OF TERRAIN ON THE LIGHT POLLUTION

We found a visible effect of the terrain on the light-island profile in cases of settlements located in the mountain areas, what affects the coverage of the distant light pollution generated by these localities. In areas with large height difference (large denivelation) the border of light-island is distinct, and the width of the transition area between the light-island and the surrounding territory is small (less than 1 km in the case of Zakopane), while in the case of the smaller height difference (small denivelation) it becomes significantly wider (in the case of Myślenice it is equal to about 4 km). This effect is particularly evident when comparing the light-islands of settlements, located in the mountain valleys (e.g. in the case of Żywiec the width of such transition area in the northern part of its light-island is equal to only around 1 km) to the light-islands of settlements located on the plain (e.g. Wadowice, for which it is equal to 4 km).

We have also found that in the case of high concentration of the particulate matter and simultaneously the cloudless sky, the measured value of S_a increases along with the increasing denivelation. We found the occurrence of this effect near the mountain villages located in the vicinity of Zakopane (the Tatra Mountains), Dobczyce (the Island Beskids) and Żywiec (the Żywiec Beskids). For all these positions the differences between the values of S_a for areas with large denivelation and such with small denivelation fall within the range of 0.4–0.5 mag/arcsec^2, which means about 1.5 fold relative decrease in brightness of the sky. We have not observed this effect in the case of fully overcast sky and simultaneously the low level of the particulate matter. We believe that an uneven terrain reduces the effect of the local ground-lighting on the brightness of the night sky, this way reducing the local light pollution. This problem requires further research.

ILLUMINATION OF THE SURFACE

The influence of ground illumination by the moonlight [8, 9] or urban lights [17, 20] on the animal behavior has been stated.

In order to determine the dependence of the ground illumination on the value of S_a we made the measurements of the illuminance of the ground by use of the specialized lux meter. It was determined that the illuminance of the ground equal to 0.1 lux (equivalent to the illumination by the full Moon) occurs at a value of S_a = 17.1 mag/arcsec^2 (15.61 mcd/m^2), and the extrapolated value equal to 0.01 lux (equivalent to the illumination by a quarter moon) occurs in the case of S_a = 20.6 mag/arcsec^2 (0.62 mcd/m^2) [24].This means that even in the case of Class II areas, the illumination by a fully overcast sky is greater than the average illumination during the lunar night. In the case of Class III areas the illumination of the ground is always greater than the illumination during the lunar night, for the overcast sky approaching even to the illumination by the full moon. In the case of Class IV areas the ground illumination is at most time comparable to the illumination by the full moon. It should be noted that in contrast to almost a point source of light, which is the Moon, in the case of the distant light pollution the source of light is the whole sky, and in the case of the local light pollution even the whole environment. In both cases the result is virtually the lack of shadow.

SUMMARY

It was found that the mountain areas in Poland, even in places not directly adjacent to urban centers, do not retain the original, natural darkness, mainly due to the distant light pollution. In the case of overcast skies the sources of the light pollution are clouds, whose influence is visible especially for positions close to the urban centers. An example might be Przesieka (position PRZ) located just 3 km from the borders of the Karkonosze National Park, where for the overcast sky we stated the value of S_a = 19.3 mag/arcsec^2 (2.06 mcd/m^2). The source of light pollution in this case is 11 km distant Jelenia Góra. A similar effect also occurs in Zakopane, on the northern border of the Tatra National Park (the “Droga pod Reglami” path), where at the same circumstances we found S_a = 18.9 mag/arcsec^2 (2.97 mcd/m^2). In both cases the illumination of the ground by the distant light pollution is similar to the illumination by the Moon between the full and quarter and there is no shadow effect. This phenomenon undoubtedly has a strong influence on the behavior of nocturnal animals and can be one of the reasons of nocturnal insects decline, stated in the Tatra National Park.

In the case of a cloudless sky, the main factor causing light pollution is the local lights, scattered by mist and particulate matter, called by us the local light pollution. This effect, particularly important in autumn and winter, when it is able to reduce the value of S_a for a few mag/arcsec^2, we found in Zakopane at the northern boundary of the Tatra National Park. We found also the effect of reducing the local light pollution with the increasing terrain height difference.

In addition to the definite influence of light pollution on local ecosystems, its impact on human health is also known [11, 12, 13, 18]. Given the fact that there are many tourist resorts or even spas in the mountain areas, which should provide adequate rest comfort, one should consider the impact of the described effect on the quality of rest and treatment in these centers.

In this study we confirmed the data presented on a model map of light pollution [5] (Fig. 3). Of the mountain areas in Poland only the Bieszczady Mountains maintain the original darkness of night, all other areas are light polluted to varying degrees. In the case of the Beskidy Mountains the distant light pollution dominates, the source of which are large cities such as Bielsko-Biała, Cracow, Tarnów, Nowy Sącz and Sanok; in the Tatra Mountains and the Żywiec Beskids the light pollution sources are also cities located within these areas, such as Żywiec and Zakopane, which are also sources of the local light pollution, however, reduced by a diverse terrain.

In the case of the Sudetes Mountains the main source of light pollution is the city of Jelenia Góra, which lying near the border of the Karkonosze National Park impacts on the environment not only indirectly through the distant light pollution, but also directly by the local light pollution. The second example can be the city of Wałbrzych, through the intense distant light pollution affecting the environment in a large area of Central Sudetes.

In all these cases the use of proper lighting in urban centers would bring a rapid improvement of the environment. An example of the effectiveness of such activities is the share reduction of light pollution in the northern regions of Chile carried out in

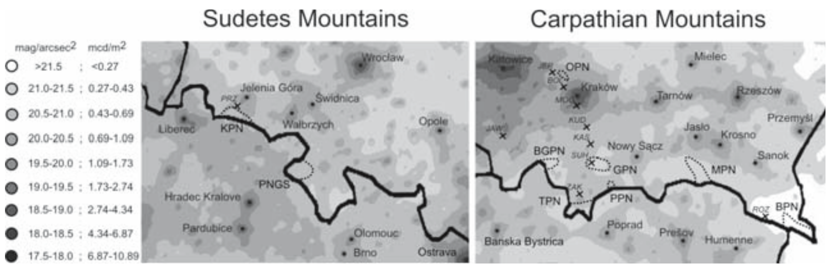

Fig. 3. Fragments of a model map of light pollution in Europe [Cinzano 2001b], including the Polish mountains (as in 1997). On the left side the scale of S_a is given. Major cities and the boundaries of Polish national parks were depicted: KPN – Karkonosze NP, PNGS – Table Mountains NP, OPN – Ojców NP, BGPN – Babia Góra NP, TPN – Tatra NP, GPN – Gorce NP, PPN – Pieniny NP, MPN – Magura NP, BPN – Bieszczady NP.

1999–2006 [21]. In Poland, a similar share had already been initiated within the "Dark Sky Area" in the commune Jeleśnia in the Żywiec Beskids (www.ciemneniebo.pl).

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REFERENCES

[1] Allen, J.A. (1880). *Destruction of birds by light-houses*, Bulletin of the Nuttall Ornithological Club, **5**, 131–138.

[2] Benn, C.R., Ellison, S.L. (1998). *La Palma night-sky brightness*, La Palma Technical Notes, No. 115 http://www.ing.iac.es/Astronomy/observing/manuals/man_tn.html.

[3] Biuletyn WIOŚ. Wojewódzki Inspektorat Ochrony Środowiska w Krakowie, http:\\www.krakow.pios.gov.pl\biuletyn.php.

[4] Cinzano, P., Falchi, F., Elvidge, C.D. (2001). *Naked eye star visibility and limiting magnitude mapped from DMSP-OLS satellite data*, Monthly Notices of the Royal Astronomical Society, **323**, 34–46.

[5] Cinzano, P., Falchi, F., Elvidge, C.D. (2001). *The first World Atlas of the artificial night sky brightness*, Monthly Notices of the Royal Astronomical Society, **328**, 689–707.

[6] Electricity and English song birds. (1897). Los Angeles Times, September 14, 7.

[7] Garstang, R.H. (1989). *Night-Sky Brightness at Observatories and Sites*, Publications of the Astronomical Society of the Pacific, **101**, 306–329.

[8] Jerling, H.L., Wooldridge, T.H. (1992). Lunar influence on distribution of a calanoid copepod in the water column of a shallow, temperate estuary, *Marine Biology*, **112**, 309–312.

[9] Jung, J., Hojnowski, C., Jenkins, H., Ortiz, A., Brinkley, C., Cadish, L., Evans, A., Kissinger, P., Ordal, L., Osipova, S., Smith, A., Vredeveld, B., Hodge, T., Kohler, S., Rodenhouse, N., Moore, M. *Diel vertical migration of zooplankton in Lake Baikal and its relationship to body size*. In Smirnov, A.I., Izmest'eva, L.R. (Eds.) *Ecosystems and Natural Resources of Mountain Regions. Proceedings of the first international symposium on Lake Baikal: The current state of the surface and underground hydrosphere in mountainous areas* (pp. 131–140). Nauka, Novosibirsk.

[10] Kaszowski, W., Ścieżor, T., Kubala M., Dworak, T.Z. (2010). *Wpływ warunków meteorologicznych na sztuczną poświatę niebieską*, Ochrona powietrza w teorii i praktyce, 103–112.

[11] Kloog, I., Haim, A., Portnov, B. (2008). *Using kernel density function as an urban analysis tool Investigating the association between nightlight exposure and the incidence of breast cancer in Haifa, Israel*, Computers, Environment and Urban Systems, **33**, 55–63

[12] Kloog, I., Haim A.,Stevens, R., Barchana, M., Portnov, B. (2008). *Light at night co-distributes with incident breast but not lung cancer in the female population of Israel*, Chronobiology International, **25**, 65–81.
[13] Kloog, I., Haim, A., Stevens, R., Portnov, B. (2009). *Global co-distribution of Light at Night (LAN) and cancers of prostate, colon, and lung in men*, Chronobiology International, **26**, 108–125.
[14] Kolláth, Z. (2008). *Wpływ światła sztucznego na Zselic Lanscape Protection Area*, Przegląd Elektrotechniczny, **84**, 76–79.
[15] Kolláth, Z. *Sky Quality Meter monitoring of the night sky at the Zselic Landscape Protection Area*, Dark Sky Awarness, http://www.darkskiesawareness.org/sqm-zlpa.php
[16] Kubala, M., Ściężor T., Dworak, T.Z., Kaszowski, W. (2009). *Zanieczyszczenie świetlne w obszarze aglomeracji krakowskiej*, PolishJournal of Environmental Studies, **18**, 194–199.
[17] Moore, M.V., Pierce, S.M., Walsh, H.M., Kvalvik, S.K., Lim, J.D. (2000). *Urban light pollution alters the diel vertical migration of Daphnia*, Verhandlungen des Internationalen Verein Limnologie, **27**, 1–4.
[18] Navara, K.J., Nelson, R.J. (1976). *The dark side of light at night: physiological, epidemiological, and ecological consequences*, Journal of Pineal Research, **43**, 349–352.
[19] Patat, F. (2003). *UBVRI night sky brightness during sunspot maximum at ESO-Paranal*, Astronomy and Astrophysics, **400**, 1183–1198.
[20] Rich. C., Longcore. T. (2005) (Eds) *Ecological consequences of artificial night lighting*, Island Press.
[21] Sanhueza, P., Schwarz, H.E., Smith, M.G. (2007) *The OPCC experience in protecting the skies of northern Chile*, *StarLight: A Common Heritage*, 427–434.
[22] Squires, W.A., Hanson H.E. (1918) *The destruction of birds at the lighthouses on the coast of California*, Condor, **20**, 6–10.
[23] Ściężor, T. (2005). *Problem środowiskowego zanieczyszczenia świetlnego oraz zastosowanie amatorskich obserwacji astronomicznych dla określenia jego wielkości*. Czasopismo Techniczne, **102**, 145–164.
[24] Ściężor, T., Kubala, M., Kaszowski, W., Dworak T.Z. (2010). *Zanieczyszczenie świetlne nocnego nieba w obszarze aglomeracji krakowskiej. Analiza pomiarów sztucznej poświaty niebieskiej*, Wydawnictwo Politechniki Krakowskiej.
[25] Taylor, V.A., Jansen, R.A., Windhorst, R.A. (2004). *Observing Conditions at Mount Graham: Vatican Advanced Technology Telescope UBVR Sky Surface Brightness and Seeing Measurements from 1999 through 2003*, Publications of the Astronomical Society of the Pacific, **116**, 762–777.
[26] Verheijen, F.J.(1960). *The Mechanisms of the Trapping Effect of Artificial Light Sources Upon Animals*, Archives Néderlandaises de Zoologie, **13**, 1–107.
[27] Verheijen, F.J. (1985). *Photopollution: artificial light optic spatial control systems fail to cope with. Incidents, causation, remedies*, Experimental Biology, **44**, 1–18.

ZANIECZYSZCZENIE ŚWIETLNE W OBSZARACH GÓRSKICH W POLSCE

Istnienie obszernej ewidencji wpływu jasności nocnego nieba na zachowania zwierząt w ich środowisku naturalnym wskazuje na potrzebę zbadania skali zjawiska sztucznie indukowanej poświaty nocnego nieba (zanieczyszczenia świetlnego) w obszarach chronionych.

Przedstawiono wyniki wieloletnich pomiarów jasności nocnego nieba, przeprowadzonych w wybranych punktach obszarów górskich Polski w różnych warunkach atmosferycznych. Przeprowadzone pomiary świadczą o wyraźnym wpływie sztucznej poświaty niebieskiej na jasność nocnego nieba, co stanowi istotę zanieczyszczenia świetlnego. Stwierdzono wpływ zarówno dalekich ośrodków miejskich, jak i lokalnych ośrodków turystycznych na wielkość badanego zjawiska w obszarach górskich, co powoduje degradację zarówno pod względem ekologicznym, jak i turystycznym tych terenów. W części badanych obszarów jasność nocnego nieba znacznie przekracza wielkość wywołaną przez zjawiska naturalne i jest porównywalna do wartości mierzonych wewnątrz miast. Stwierdzono, że jedynie południową część Bieszczadów można uznać za obszar wolny od zanieczyszczenia świetlnego.