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An environmental index of noise and light pollution at EU by spatial correlation of quiet and unlit areas☆

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ABSTRACT

Quietness exists in places without human induced noise sources and could offer multiple benefits to citizens. Unlit areas are sites free of human intense interference at night time. The aim of this research is to develop an integrated environmental index of noise and light pollution. In order to achieve this goal the spatial pattern of quietness and darkness of Europe was identified, as well as their overlap. The environmental index revealed that the spatial patterns of Quiet and Unlit Areas differ to a great extent highlighting the importance of preserving quietness as well as darkness in EU. The spatial overlap of these two environmental characteristics covers 32.06% of EU surface area, which could be considered a feasible threshold for protection. This diurnal and nocturnal metric of environmental quality accompanied with all direct and indirect benefits to human well-being could indicate a target for environmental protection in the EU policy and practices.

1. Introduction

Noise is one of the dominant contemporary environmental problems affecting human health and wellbeing (EEA, 2014; Fyhri and Aasvang, 2010; WHO, 2002; Zaharna and Guilleminault, 2010), as well as wildlife conservation (Barber et al., 2010). In an attempt to mitigate noise pollution the European Commission introduced in 2002theDirective 2002/49/EC regarding the assessment and management of environmental noise (END). According to END environmental noise is the unwanted or harmful outdoor sound created by human activities, including noise emitted by means of transport and sites of industrial activity. END served as a platform to boost research on environmental noise and led to the development of new tools and methodologies to achieve environmental noise mapping. The END interim report recommended computation methods of assessment, common for all Member States (Manvell and van Banda, 2011). Still, noise pollution continues to threaten about 40 million people living in cities and 25 million people in open-country (EC, 2011), without excluding others exposed at lower sound levels, than the ones documented to cause health problems (WHO, 2011).

The designation and protection of Quiet Areas (QAs) constitute a major policy initiative to confront noise pollution. QAs could be considered as sites where people can recover from harmful noise pollution effects (Brambilla and Maffei, 2006) and wildlife is protected (Barber et al., 2011; Hatch and Fristrup, 2009; Reed and Merenlender, 2008). Focusing on open country, QAs are places without human-induced noise sources (i.e. traffic, agglomerations, industries, constructions, recreational activities), constituting refuges of noise pollution. END, as well as recent studies (De Coensel and Botteldooren, 2006; Licitra et al., 2011; Shepherd et al., 2013) have underscored the role of open country QAs for safeguarding environmental quality. And outside EU, research documented that QAs could form an indicator of remoteness and potential wilderness (Carver et al., 2013; Landres et al., 2008). Hereafter in this paper QAs refer to QAs in open country.

Light pollution, on the other hand, forms another important environmental problem affecting 37% of the European population (Cinzano et al., 2001; Marin, 2009). Considering the role of light as a resource (photosynthesis, diurnal activities, repair and recovery), as well as an information source (visual perception, spatial orientation), the impacts of artificial lights are manifold for human well-being and for wildlife (Davies et al., 2013; Gaston et al., 2013). Among them the increase of mortality and decrease of fecundity resulting in changes in species composition and trophic structure are the most significant for a wide range of plants and animals (Lyytimäki et al., 2012; Rodrigues et al., 2012). As far as human

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effects are concerned, many researchers have recorded sleep, asthma, even cancer related problems (Bephage, 2005; Kloog et al., 2009; Lin et al., 2001). While noise pollution is usually associated with diurnal activities and only rarely with nocturnal activities, artificial light pollution refers primarily (if not exclusively) to nocturnal activities.

Recently various initiatives to measure and mitigate light pollution have been developed [e.g.2009/125/EC,International Dark Sky Association, Albers and Duriscoe (2001), Aubé, and Roby, 2014, Duriscoe (2016), Kyba et al. (2013, 2015), Pun and So (2012)]. In environmental studies, however, it is rather difficult to measure light pollution impacts adopting standard methods (Longcore and Rich, 2004). An alternative and easy to implement approachto quantify the effects of light pollution on humans and the environment is to identify artificial lights and isolate them afterwards, so as to define theUnlit Areas (UAs), i.e. areas without artificial light. Hölker et al. (2010), and Gaston et al. (2012) suggest to study the implications of Darkness as this would significantly contribute to future conservation efforts. These unlit refuges are characterized by lack of intense human interference, thus composing areas where naturalness prevails (Carver et al., 2013; Gaston et al., 2012; Landres et al., 2008).

To sum up, noise and artificial light constitute human induced environmental pollutions, whereas QAs as well as UAs could potentially offer the desired tranquility for human societies and nature conservation (Carver et al., 2013; Chalkias et al., 2006; Hölker et al., 2010). Noise pollution reduces human wellbeing and disturbs the wildlife, while light pollution has similar effects only at nighttime. The objective of this paper is to investigate the pattern of noise and light pollution aiming to develop an integrated diurnal and nocturnal index of these two forms of environmental pollution. This environmental index includes 4 different cases: a) areas free of noise and light pollution, b) areas with noise pollution but no light pollution, c) areas with light pollution but no noise pollution and d) areas with noise and light pollution. To prove this concept, we applied the environmental index at the member-States of the EU in order to contribute in a preliminary time and cost effective way to conserving high ecological value areas as well as ensuring human wellbeing.

2. Material and methods

2.1. Study area

All spatial data, their investigation, as well as their interpretation included the 27 Member-States of the EU, before Croatia' joining. Europe is a continent with a long history of human activities. It is densely populated, with high degree of light and noise pollution, and complex, vastly fragmented landscapes (Jaeger et al., 2011).

2.2. Identifying areas without noise & light pollution

Noise mapping software is, today, a professional well-developed and commonly used tool based on specific standards for various purposes (Manvell and van Banda, 2011; Ramis et al., 2003; WGAEN, 2007). Nevertheless our goal was to identify QAs at a coarse scale, i.e. quiet areas in open country. QAs assessment requires specialized methodology (Clarke, 2011; MacFarlane et al., 2004; Morgan et al., 2006; Symonds, 2003; SWS, 2000; Waugh et al., 2003). Under this framework EEA proposes a multi-dimensional methodological approach of QAs suitability which is based, among others, on distance-based criteria. Indeed, EEA proposes the adoption of different criteria for QAs in cities and in open country (EEA, 2016). For QAs in agglomerations, noise mapping is the recommended approach, even recognizing its limitations, i.e. noise mapping does not distinguish pleasant (water falling, birds singing) from annoying (cars, airplanes) sounds, just records sound pressure levels (EEA, 2014). But this approach is demanding in man power and time and its level of accuracy is not necessary at coarse continental scales (as in the present study).

Here, we applied the methodological designation of QAs in open country based on distance criteria (Votsi et al., 2012, 2015), also supported by EEA (2014; 2016). In this approach, the basic human induced noise sources are located using several spatial datasets [Corine Land Cover (2000), Open Street Map (daily updated), Urban Atlas (2006)], and each noise source is associated with recorded energy equivalent sound pressure levels at the noise source based on calculating the average noise source for each category of existing literature reviews. The model also includes the computation of the cumulative effect of noise sources, as well as the noise source standardization to human response according to the dose-response relationship (Schomer, 2005). The next step comprised buffering each noise source, taking into account the mean radius value that is needed for the sound pressure level of each source to fall below the critical threshold of Quietness (50 dB of Lden). Noise propagation was calculated following the basic principles of Acoustics, according to which sound pressure level decreases in inverse proportion to the distance from source, meaning that doubling the distance from a noise source the sound pressure is reduced to half of the initial value (Pierce, 1989). For a thorough documentation of the input data layers and the methodological approach to define QAs please consult Table 1. By overlaying the buffered noise sources onto a map of EU, we defined QAs (Fig. 1a). Of course this is a simplification, which limits the accuracy of the QA delineation, but it is proposed as a fast and economic first approximation to estimate the QAs.

Our methodological approach is based on the assumption that the different databases used provide data about the distribution of the sound sources referring to the previous decade. This was because the required information (of both noise and light pollution) was available only for that time period. This means that the analysis refers to that dates, and it remains an open question for future research, if and where conditions changed significantly enough in the intervening time. Some first indications from the Noise Observation and Information Service for Europe indicate that there are significant changes in countries such as the UK and France (http://noise.eionet.europa.eu/viewer.html), but the degree to which they affect the continental scale patterns of quiet areas or are more limited and localized remains open question for future research.

Though in the case of noise pollution, no available noise mapping of the EU territory exists, a database on lights observed by satellite images was derived from NOAA (F15 2003 Nighttime Lights Composite) (NOAA, 2015) in the format of raster data. This data also refer to the same time period as the noise data. A number of constraints were used to select the highest quality data. The cleaned up dataset includes city lighting as well as other sites with persistent lighting, including gas flares. There are no ephemeral events and the background noise was identified and replaced with values of zero (DM Duriscoe et al., 2013). (available at: http://ngdc.noaa.gov/eog/dmsp/downloadV4composites.html).

In the case of noise pollution we had to determine and calculate the expansion of each noise source, whereas in the case of light pollution the influenced area around each light source is delineated directly using satellite images. The NOAA data depict the actual area influenced by artificial lighting, with an efficient accuracy for a coarse scale research (Elvidge et al., 2013; Bruehlmann, 2014), enabling use to derive the UAs. We then reclassified the observed data into a binary raster map depicting with value one the lights of