

SPATIAL ASSESSMENT OF NIGHTTIME ANTHROPIZATION IN THE COMOÉ NATIONAL PARK IN CÔTE D'IVOIRE (WEST AFRICA)

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Abstract

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Protected areas play a crucial role in preserving biological diversity, providing ecosystem services, and regulating hydroclimatic processes. However, the environmental balance of these areas is increasingly under threat due to rapid population growth, high demand for natural resources, and the effects of global warming. To address this, sustainable management of protected areas is essential. This study aims to develop a methodology for monitoring and assessing levels of nocturnal anthropogenic aggression in the Comoé National Park (CNP) in Côte d'Ivoire. By using geospatial data from the Day/Night Band of the Visible Infrared Imaging Radiometer Suite (VIIRS/DNB), the study characterizes the nocturnal anthropization of CNP through the use of several indices. First, light reflectance density is used to identify nighttime light emission foci. Second, the lighted area density index (LADI) is employed to understand the nature of nocturnal activities taking place within CNP, as indicated by artificial light at night (ALAN). Finally, the light intensity index (LII) is used to evaluate the degree of influence of nocturnal anthropogenic activities on biodiversity. The study also found important activities through LADI and observed a high level of light pollution in CNP. Ultimately, the findings of this study indicate that there is a significant level of nocturnal anthropization within CNP, highlighting the need for effective management and conservation efforts in the area.

Key words: Remote sensing GIS, protected areas, artificial light at night, VIIRS/DNB, Comoé National Park, Ivory Coast.

Introduction

Protected areas play a vital role in preserving biodiversity, serving as “refuges” for a wide range of species. They help maintain ecological functions, support the well-being of humanity, and are a crucial tool in preventing the extinction of threatened and endemic species (Dudley, 2008). In addition to their conservation value, protected areas also play an important role in socio-economic development, providing livelihoods for local communities and supporting economic activities (Molla, 2020). Effective management of these areas is crucial to ensure their continued ecological and socioeconomic benefits for current and future generations.

The preservation of protected areas is acknowledged as a strategy for combating climate change through carbon sequestration (Anderson, Mammides, 2020; Analiz, Joaquin, 2015; Du et al., 2015). However, with the increasing global human population, these ecologically vital resources are facing threats from overexploitation (Butchart et al., 2010; Watson et al., 2016; Venter et al., 2016b). As a result, the protection of these areas has become a major concern. Therefore, the scientific community,

policymakers, and civil society organizations all have a crucial role to play in their management. Advances in geospatial technology and computing power have enabled the generation of large volumes of data, which can inform conservation decisions at a global level (Pettorelli et al., 2014). These technologies have made significant progress in spatial monitoring and environmental characterization and have provided important indicators of human impact (Venter et al., 2016a).

Nocturnal spatial techniques provide the scientific community with new perspectives for assessing socioeconomic parameters (Shi et al., 2016), monitoring urbanization processes (Zhao et al., 2020), and observing ecological and environmental phenomena (Li et al., 2020). Monitoring human activities at night is a breakthrough that offers a deeper understanding of the impact of human activity on the environment.

In addition, the use of remote sensing techniques has made it possible to monitor ecological parameters within a reserve and assess the impact of human activities on natural resources (Adou et al., 2018; Mama et al., 2020). However, few studies have specifically addressed the issue of assessing nocturnal human pressures on protected area resources.

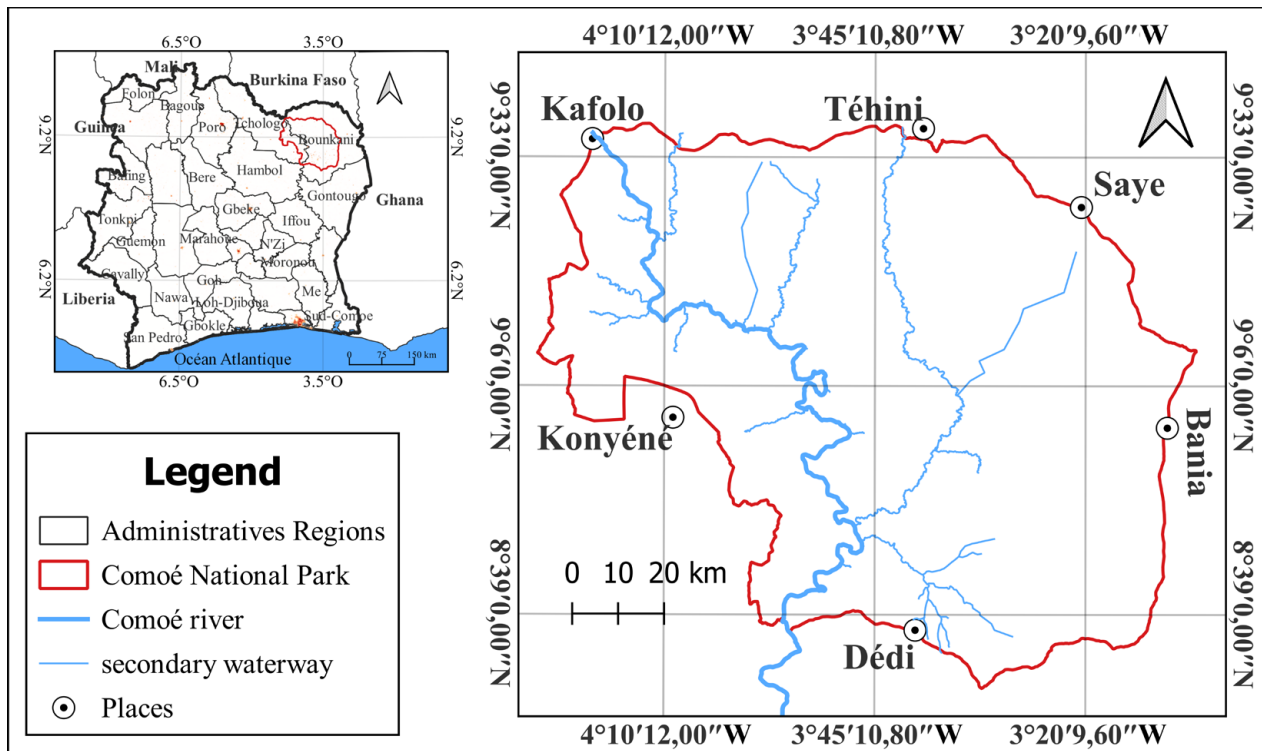


Fig. 1. Geographic location of Comoé National Park.

The Comoé National Park (CNP) is a critically important reserve for biodiversity, recognized by the United Nations Educational, Scientific and Cultural Organization (UNESCO) as a biosphere reserve in 1982 and designated as a world heritage site since 1983. Despite this recognition, the park faces significant challenges in its management, primarily due to human intrusion. To address this issue, this study proposes a new approach for characterizing anthropogenic impact through nighttime spatial monitoring. The goal is to evaluate the level of nocturnal anthropization within CNP using ALAN observations.

Material and methods

Study area

CNP (Fig. 1), with an area of 11,487.56 km², is located in the northeast of Côte d'Ivoire. Created in 1968, CNP was inscribed on the UNESCO World Heritage List in 1983. CNP is a world heritage property because of its remarkable variety of habitats, including shrub savannahs, wooded savannahs, gallery forests, and coastal grasslands that constitute an outstanding example of transitional habitats between forest and savannah. Its geographic location and vast area dedicated to the conservation of natural resources make it one of the most ecologically important parks. Its geomorphology features large plains with deep channels carved by the Comoé River and its tributaries, allowing for the ascent of ombrophilous vegetation and the presence of animal species from the forest zone. The property also hosts green rock intrusions aligned from north to south, topped by rocky bars that form isolated massifs and small chains of 500 to

600 m in altitude in the center and north. The variety of habitats results in a great diversity of animal species (Diawara, Diedhiou, 2017). Protection of CNP is governed by several national laws. The main management challenges include antipoaching, human occupation, agricultural pressure, and inadequate management control and access within the park (OIPR, 2015).

Study data

The main data used in this study are nighttime light images from the Visible Infrared Imaging Radiometer Suite (VIIRS) Day/Night Band (DNB) covering the study area. The data were obtained from National Oceanic and Atmospheric Administration / National Geophysical Data Center NOAA/NGDC (<https://www.ngdc.noaa.gov/eog/>) and were captured by the joint National Aeronautics and Space Administration (NASA)/NOAA Suomi National Polar-orbiting Partnership (Suomi NPP) and NOAA-20 satellites, with a resolution of 15². These images were used to map and understand the anthropization phenomenon of the CNP environment. The VIIRS data have been available since 2012, and for this study, we used the monthly composites. These composites come in two types of configuration: VIIRS cloud mask ("vcm") and VIIRS cloud mask stray light ("vcmsl"). The "vcm" configuration, which excludes stray light, was used in this study, as opposed to the "vcmsl" configuration, which does not exclude stray lights and provides a wider coverage of lighted areas (Elvidge et al., 2017).

The boundaries of CNP were obtained from the International Union for Conservation of Nature (IUCN) World Database of Protected Areas (WDPA) and archived by the United Nations

Environment Programme World Conservation Monitoring Centre (UNEP-WCMC). This database can be accessed online for free at <http://www.protectedplanet.net>.

Methods

In this study, three indicators were used to evaluate the level of anthropization within CNP. The first indicator, based on the method of density of nuclei (Chen, 2017), measures the density of observations of light reflections and provides insight into the foci of nocturnal light emission. The second indicator, the lighted area density index (LADI), assesses the spatial distribution of human activities based on light reflectances. The final indicator, the light intensity index (LII), estimates the degree of environmental impact by measuring light reflectance levels. To calculate these indicators, luminous reflectance values were extracted from night light images using QGIS software. Reflectance values lower than 5 nW/cm²/sr were removed to eliminate any reflectances from neighboring areas. In addition, the night light data were processed to exclude stray light from sources such as fires, lightning, the sun and moon, gas flares, and high-energy particles, to accurately highlight reflectances from human activities only (Elvidge et al., 2017).

Observation of light clusters

The observational density of light reflections is a measure that provides information on the density of nighttime human activity. However, the most commonly used density estimate is the core density estimate (Chen, 2017). This density is expressed as:

$$\hat{f} = \frac{1}{nb} \sum_{j=1}^n K\left(\frac{x - x_j}{b}\right),$$

for a sample, . . . , K() is a kernel function and b is the bandwidth b; the kernel is normally chosen as a probability density function.

Lighted area density index

This index measures the intensity of the spatial extent of nighttime human activities in a given area. LADI developed from the total nighttime light index (Jiang et al., 2017, 2018) estimates the proportion of surface exploited and the degree of influence of any light reflectance on a given area. Unlike the density of observation of light reflections, which allows locally observing the abundance of nighttime human presence, LADI allows evaluating the spatial distribution of intensities of nighttime human activities. In addition, this index is a very good indicator to evaluate potentially impacted areas of an environment. LADI is the ratio between specifically illuminated areas and the total illuminated surface. It is expressed as follows:

$$LADI_i = \left(\frac{\sum_{i=1}^n C_i * DN_i}{S_T} \right) * S_s / DN_i,$$

where is the th gray level corresponding to the pixel value and is the number of pixels that correspond to the gray level. and correspond to specific and total areas, respectively.

Light intensity index

LII allows us to evaluate the degree of influence of human activities on the ecological environment of a given area. This index allows us to evaluate the environmental footprint exerted by humans on CNP using light reflectance data. This index represents the cumulative values of light reflectance in the protected area under consideration. It is expressed as follows:

$$LII_i = \left(\frac{(\sum_{i=1}^n DN_i) * S_s}{S_T} \right) * DN_i,$$

where is the th gray level corresponding to the pixel value and is the number of pixels that correspond to the gray level. and correspond to specific and total areas, respectively.

Results

The following results are for the months with the most illuminated area. An annual analysis will present the annual evolution of these indices below.

Observation of light clusters

Examination of the density of light observations within the park provides insight into potential areas of human nocturnal activity. Data collected over the course of the years 2012–2020 indicated that light reflectances were observed throughout CNP. The frequency of these reflections commenced in November of the preceding year and continued through February, with instances of persistence into March of the subsequent year. Analysis of Figure 2 reveals a fluctuation in the focal points of emission of LNA. This fluctuation reflects a movement and substantial occupation of nocturnal human activities. The migration of LNA focal points indicates a substantial anthropogenic impact on the surface area.

Lighted area density index

The results indicated a significant level of nighttime human activity in CNP as measured by LADI, a dimensionless index. High and very high levels of nighttime human activity were significantly distributed during January 2013 and 2020, as well as in December 2014, 2016, and 2017. The period of January 2013 had the highest number of points recorded for very high levels of nocturnal human activity, with a total of 121 points identified as areas with very high-level nighttime human activity. In comparison, the periods of December 2017 and January 2020 had 57 and 71 points, respectively, indicating areas with very high levels of nighttime human activity. The previous three periods showed a wide distribution of high-level nocturnal human activities. Specifically, the periods of January 2013, December 2017, and December 2020 had 211, 171, and 100 points, respectively, corresponding to areas that experienced high-level nighttime human activity. During the periods of December 2014, 2015, and 2016, there was a significant amount of activity in the park, but it was mostly dominated by nighttime human activity ranging from very low to moderate intensity (Fig. 3).

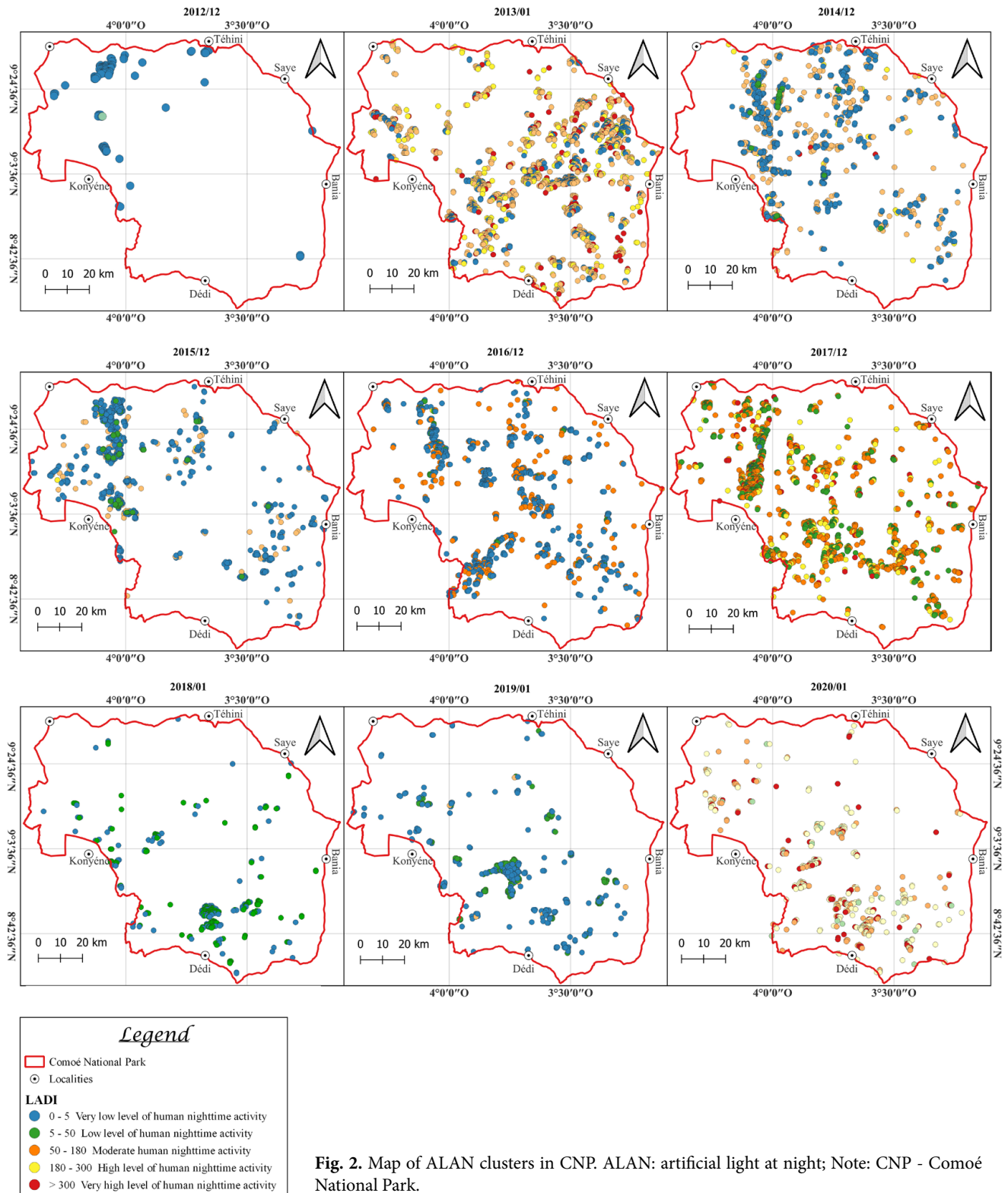


Fig. 2. Map of ALAN clusters in CNP. ALAN: artificial light at night; Note: CNP - Comoé National Park.

Light intensity index

Figure 4 presents the impact of human activities at night on the CNP ecosystem as observed through light reflectance measure-

ments. The periods of January 2013 and December 2017 showed the highest levels of light pollution in CNP. During these periods, areas of approximately 37 and 15 km², respectively, experienced very high levels of light pollution (LII greater than 15,000

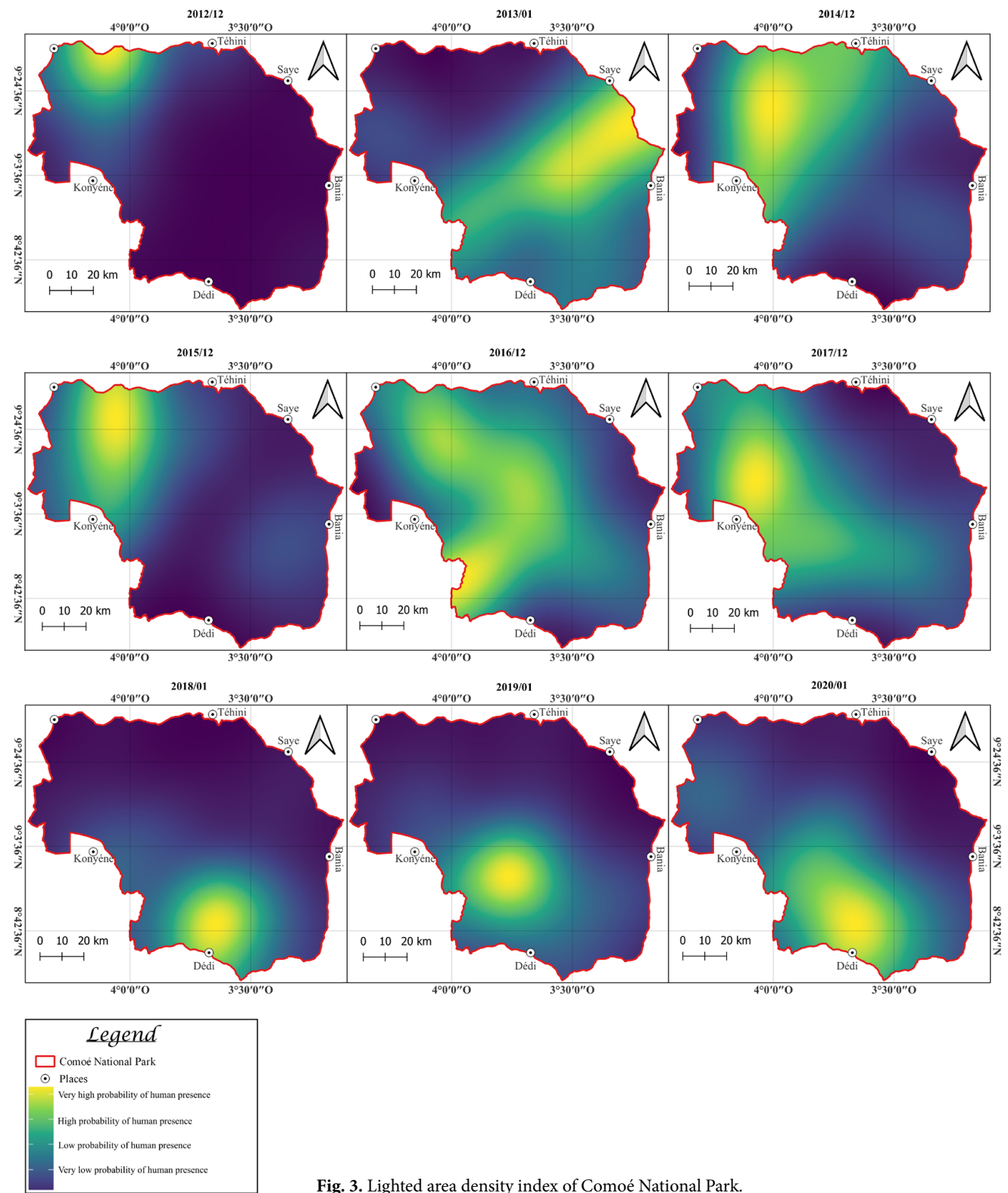


Fig. 3. Lighted area density index of Comoé National Park.

($\text{nW}/\text{cm}^2/\text{sr}^2$) in CNP, indicating a significant disturbance to the park's ecosystem. In addition, during these same periods, areas of more than 89 and 58 km^2 experienced strong light pollution corresponding to LII values between 5000 and 15,000 ($\text{nW}/\text{cm}^2/$

sr^2), representing more than 0.77% and 0.5% of the total area of the park, respectively. Overall, these areas, totaling more than 126 and 74 km^2 , have experienced a significant environmental impact in the park.

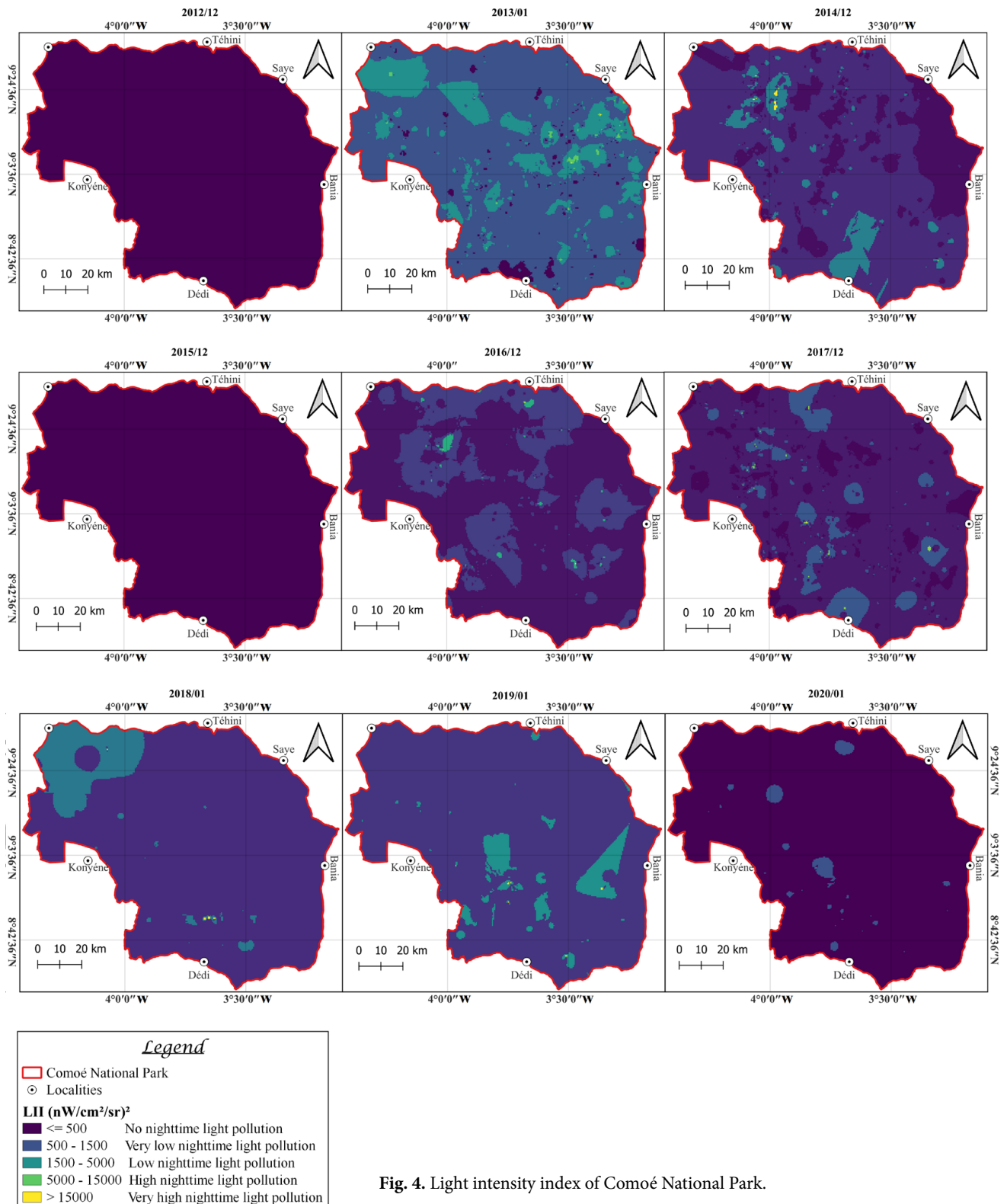


Fig. 4. Light intensity index of Comoé National Park.

Annual evaluation of the indices

Lighted area density index

Changes in human activities at night can have significant impacts on the environment, and LADI can help quantify these

changes. Figure 5 shows the annual change in LADI, which provides a better understanding of the trends in nighttime human activities over time.

The data showed a notable increase in activity rate in 2013, followed by a gradual decline in LADI through 2015. Beginning in 2016, there was a clear increase in the LADI, with a peak ob-

served in 2017. However, the trend then reversed, and the index began to decline again from 2017 to 2020.

Overall, the LADI trend analysis emphasizes the dynamic nature of human activity at night and the potential impacts on NPC environment. This information can be valuable in informing policies and practices related to managing nighttime activities in the park in a way that minimizes negative environmental impacts.

Light intensity index

Figure 6 illustrates the distribution of pollution levels determined using LII. In 2012, no areas contaminated by nighttime activities were detected, as all LII values were below $500 \text{ (nW/cm}^2/\text{km}^2)^2$. However, in 2013, 2015, and 2017, very high pollution levels ($\text{LII} > 15,000 \text{ (nW/cm}^2/\text{sr}^2)$) were observed, occupying estimated areas of 0.24, 0.64, and 0.08 km^2 , respectively. These areas represent a very small percentage of the total area, with 0.0021%, 0.0056%, and 0.0007% determined in 2013, 2015, and 2017, respectively, based on previously recorded data. In 2013, a significant area of 11.20 km^2 was polluted by high levels of LII ($5000 < \text{LII} < 15,000 \text{ (nW/cm}^2/\text{sr}^2)$), which decreased to 3.52 km^2 in 2017.

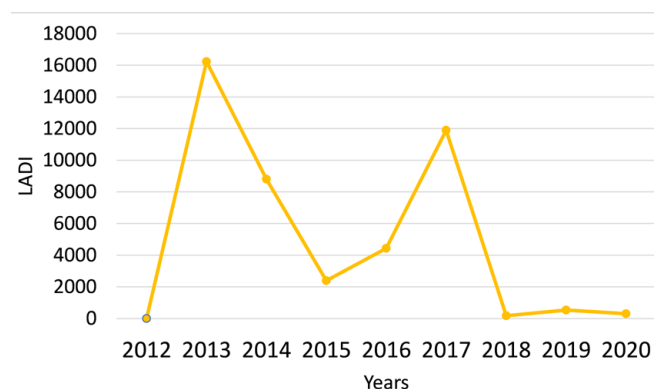


Fig. 5. Annual distribution of lighted area density index (LADI) and surface reflectance index.

Despite the predominance of unpolluted and low-polluted areas, the existence of high and very high levels of pollution reflects a considerable level of nocturnal activity and its significant impact on the environment of CNP.

Discussion

Observation of night light in the park

ALAN has been a widely discussed topic in the literature (Bennie et al., 2014; Gaston et al., 2015; Guette et al., 2018). This study aimed to assess the level of nocturnal anthropization in CNP by observing ALAN as an indicator of human presence. Subsequently, the level of light pollution caused by this nocturnal anthropization was estimated. The data used in this study were processed to remove any nonhuman sources of reflectance, such as combustion, sunlight, moonlight, gas flares, and high-energy particle reflectances (Elvidge et al., 2017). This ensured that the observed reflectances were solely a result of human activities. The study found significant nocturnal anthropization in CNP, as indicated by LADI. This finding is consistent with previous studies, such as the one by Zheng et al. (2021), which found a high level of aggression in African protected areas using VIIRS images. It is well established that ALAN in protected areas can have negative impacts on ecological balance and biodiversity (Xiang, Tan, 2017).

CNP is faced with several forms of aggression on its biodiversity, such as:

- clandestine gold panning,
- uncontrolled hunting,
- poaching,
- illegal fishing, etc.

All these forms of aggression were noted during reactive monitoring missions in 2013 and 2017 (UNESCO/IUCN, 2017; Djafarou, José, 2013).

This study unveils a significant level of light pollution in CNP, which can have profound consequences on the surrounding ecosystems. The introduction of ALAN results in substantial disturbances at the ecological level and has an impact on species diversity. This assertion is backed by several researchers who argue that light exerts a profound influence on the biological functioning of fauna and flora (Bennie et al., 2014; Cinzano, Falchi,

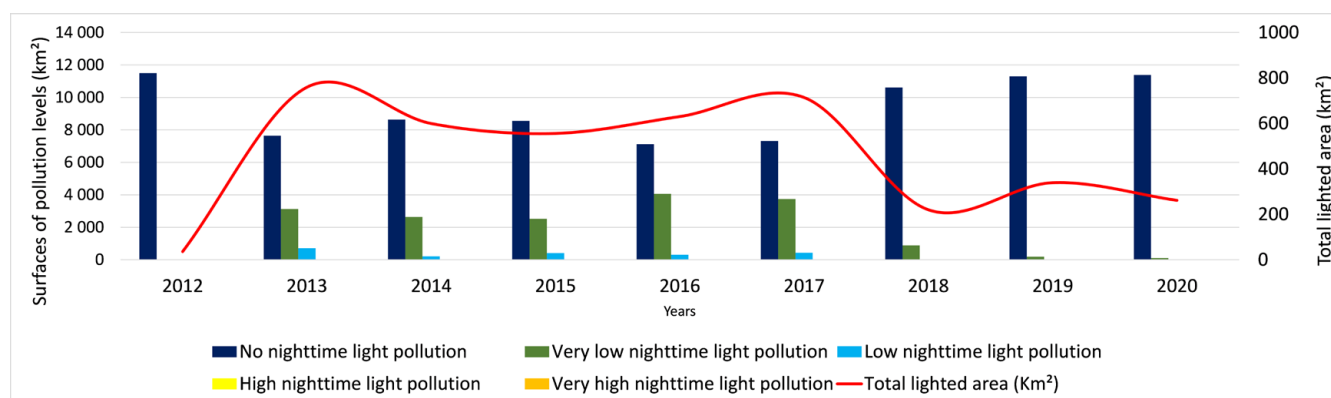


Fig. 6. Annual variation of the annual light intensity index.

2014; Singhal et al., 2021). ALANs have been found to negatively affect the abundance, distribution, and ecosystem function of light-sensitive species, posing a threat to biodiversity and hastening species extinction (Aubrecht et al., 2010). These findings are further corroborated by a similar study conducted by Jiang et al. (2018) in protected areas of China, where elevated pollution levels were observed across a substantial number of protected areas.

The periods of observation for nighttime lights were between the months of November of the current year and March of the previous year. In addition, light reflectances were observed during the dry season. This period generally corresponds to the fruit harvest period and when the trees have lost their foliage. It is more difficult to observe these lights during the rainy seasons that begin in March, due to the increased foliage density and the resolution of the satellite, which is 15².

The purpose of the developed indices

The characterization of nocturnal human activities was conducted using the LADI and LII indices. These indices provide a means to evaluate the extent of nocturnal anthropization in an area. Analysis of these indices in CNP revealed a notable degree of nocturnal anthropization, with significant impacts on the environment of CNP. The assessment of activity levels within the park was estimated based on the intensity of light reflectance, which aligns with the findings of the joint UNESCO/IUCN mission that identified the considerable presence of human activities such as gold panning, fishing, and illegal hunting in the area (Diawara, Diedhiou, 2017).

Limits

This study presents a characterization of nocturnal anthropization within CNP, offering valuable insights for park managers, partners, and policymakers. In addition, the methodologies employed in this study can be utilized to assess the anthropic status of other protected areas. However, it is important to acknowledge that the implementation of this study in protected areas with dense vegetation cover may encounter challenges. The VIIRS/DNB data used to capture artificial night lights at a resolution of 500 m (Ivan et al., 2020) have limited sensitivity to detect light signals in forested environments and during the rainy season, making characterization in such conditions difficult.

Conclusion

This study characterized the state of nocturnal anthropization in CNP and the influence of human activities at night using two indicators: LADI and LII. The results of LADI indicate a high level of human occupation in CNP during nighttime hours, with considerable intensity levels. LII also revealed the level of impact of these activities on the park environment, showing a significant environmental footprint on CNP. Therefore, sustainable and effective management of CNP is crucial, and it necessitates the enhancement of its nighttime surveillance. Furthermore, the generation of new data versions with higher resolutions would be a valuable asset in preserving protected areas with dense vegetation cover.

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