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Estimating population and energy consumption in Brazilian Amazonia using DMSP night-time satellite data

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Abstract

This paper describes a methodology to assess the evidence of human presence and human activities in the Brazilian Amazonia region using DMSP/OLS night-time satellite sensor imagery. It consists on exploring the potential of the sensor data for regional studies analysing the correlation between DMSP night-time light foci and population, and the correlation between DMSP night-time light foci and electrical power consumption. In the mosaic of DMSP/OLS night-time light imagery from September 1999, 248 towns were detected from a total of 749 *municípios* in Amazonia. It was found that the night-time light foci were related to human presence in the region, including urban settlements, mining, industries, and civil construction, observed in ancillary Landsat TM and JERS imagery data. The analysis considering only the state of Pará revealed a linear relation ($R^2 = 0.79$) between urban population from the 1996 census data and DMSP night-time light foci. Similarly, electrical power consumption for 1999 was linearly correlated with DMSP night-time light foci. Thus the DMSP/OLS imagery can be used as an indicator of human presence in the analysis of spatial–temporal patterns in the Amazonia region. These results are very useful considering the continental dimension of Amazonia, the absence of demographic information between the official population census (every 10 years), and the dynamics and complexity of human activities in the region. Therefore

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DMSP night-time light foci are a valuable data source for global studies, modelling, and planning activities when the human dimension must be considered throughout Amazonia.

Keywords: DMSP/OLS night-time light; Human settlements; Urban population; Electrical power consumption; Urban Amazonia; Spatial analysis; Regional scale

1. Introduction

The Brazilian Amazonia supports the world's largest contiguous area of untouched tropical forest. However, recent estimates show deforestation rates of 1–3 million ha $year^{-1}$ for the period of 1991–1999 and the loss of approximately 60 million ha of forest by 2000 (INPE, 2002). The deforested area of the Brazilian Amazonia has increased from 10 million ha in the 1970s to nearly 59 million ha in 2000, as a consequence of the construction of an extensive road network and government-assisted migration and agrarian projects. Alves (1999) showed that 90% of the total deforestation in Amazonia has been concentrated within a 100 km^2 land zone around major roads, increasing the environmental and social impact in such areas.

During the last three decades, the Amazonia region has experienced the highest urban growth rates in Brazil. [1] In 1970, urban population comprised 35.5% of the total population. This proportion increased to 44.6% in 1980, to 58% in 1991, to 61% in 1996, and to 68% in 2000. [2] The increasing diversity in economic activities and the subsequent increase in the population density have reorganized the network of human settlements all over the region. Current 21st century data show patterns and spatial arrangements that reveal a different Amazonia from the last decades. This new Amazonia emerges as a tropical forest with a complex urban system, a perspective that has led some researchers to put forward the claim for an "urbanized forest" (Becker, 1995).

Measures of urban growth and population in Amazonia however have been dependent on census data, collected typically on a 10-year interval. Additionally, census tracts in the region frequently cover a mixture of urbanized areas and large uninhabited ones, making it difficult to produce realistic representations of the spatial distribution of the population. The spatial and temporal dimensions of the occupation processes in Amazonia suggest the use of remote sensing data provided by the Defense Meteorological Satellite Program (DMSP), with the Operational Linescan System (OLS). The OLS sensor is particularly interesting because it is

[1] For this paper, we adopted the IBGE (Brazil's Census Bureau) surveys definition for *urban population*: every people which domicile is located inside of urban perimeter (defined by law) are counted as urban population (IBGE, 1995).

[2] Population data for this paper was obtained from IBGE surveys.

sensible to faint night-time light. It generates images with wide swath, and its images are provided with spatial resolution of up to 1.0 km. The night-time satellite sensor data provided by the DMSP/OLS have been used for global/continental urban mapping, showing linear relations with other socio-economic variables such as population, Gross Domestic Product, and electrical power consumption (Elvidge, Baugh, Kihn, Kroehl, & Davis, 1997a; Imhoff et al., 1997; Sutton, Roberts, Elvidge, & Meij, 1997).

This paper employs DMSP/OLS imagery to identify human presence in Brazilian Amazonia. Two questions have arisen: (1) in a regional scale, how can the DMSP/OLS images help to identify the relation between spatial distribution of population and the energy consumption? (2) What restrictions and limits are due to DMSP as data source?

2. DMSP/OLS in urban mapping and human activity detection

The US Air Force Defense Meteorological Satellite Program (DMSP), which includes the OLS—an oscillating scan radiometer capable of detecting visible and thermal-infrared emissions, has been in operation since the 1970s. The spatial resolution of 2.8 km at full mode, and 0.56 km at fine mode, associated with approximately 3000 km of swath, enables the synoptic coverage of large areas. Using a photo multiplier tube (PMT) at night, the visible spectral band (0.47–0.95 μm) makes the sensor very sensitive to faint VNIR emission sources (Elvidge, Baugh, Kihn, Kroehl, Davis, & Davis, 1997b) such as those produced by the night-time light of cities, towns, fires, lightning, etc. The high contrast between lighted and unlighted areas and the sensor's spatial resolution makes it a useful tool to identify regions of intense human activity (Croft, 1973, 1978).

Early attempts to use a single data acquisition of DMSP/OLS imagery to map the distribution of human settlements and the spatial distribution of human activities, such as energy consumption were hampered due to problems of pixel saturation and blooming, cloud cover, and the presence of ephemeral light sources such as lightning and fires (Foster, 1983; Welch, 1980; Welch & Zupko, 1980). The problem with ephemeral lights and cloud cover has been solved by the NOAA/NGDC (National Oceanic and Atmospheric Administration's National Geoscience Data Center), which developed a methodology to generate stable light data sets. This method includes the collection, rectification, and aggregation of a large number of night-time OLS images. The image time series analysis distinguishes stable lights produced by cities, towns, and industrial facilities from ephemeral lights. This methodology also accounts for cloud screening and ensures sufficient cloud-free observations to determine the location of all VNIR emissions (Elvidge et al., 1997b). The result is an image whose values are percentages of night-time light occurrences for each pixel. These images, used by Imhoff et al. (1997) to map urban areas in the United States, have identified the lowest threshold value in the urban/not urban classification that maintains the urban core as a unit. Compared to the urban areas from the 1990 US Census, the urban area from DMSP night-time light was only 5% smaller.

Sutton et al. (1997) has obtained a quantitative relationship between the intensity of DMSP night-time light and the population density for cities of the continental United States. Adjacent saturated pixels were grouped in "urban clusters" and the ratio of the "urban clusters" areas and the population, results the human population density (HPD). A linear regression between HPD and night-time DMSP imagery, produces a coefficient of determination of 0.84. For an exponential regression, the same coefficient results 0.93.

Elvidge et al. (2001) concluded that DMSP night-time light is a feasible alternative to identify urban settlements on a global scale in Landsat TM-class (30 m spatial resolution) images. Lighted areas were correlated with population, gross domestic product, and energy consumption of 21 countries with different economies. Linear relation with population produces $R^2 = 0.85$, where the outliers were countries with poor economies. Similarly, electrical power consumption and gross domestic product result $R^2 = 0.96$ and $R^2 = 0.97$, respectively. These results suggested that DMSP/OLS imagery could be used to infer the global population spatial distribution, with a proper regional or national calibration. Doll, Muller, and Elvidge (2000) have observed that night-time light data were related to CO_2 emission parameters on a global scale, as a proxy of development and urbanization with a statistically significant correlation with gross domestic production (GDP) and total carbon dioxide emission.

DMSP/OLS data have also been used to produce a worldwide population database to estimate population at risk in the LandScan Project (Dobson, Bright, Coleman, Duree, & Worley, 2000). The distribution of the population in the LandScan project represents an ambient population that joints diurnal movements and collective travel habits in a single measure. DMSP night-time light, associated with road proximity, slope, and land cover, defined the probability coefficients that assigned census available counts in a population density surface for the entire world.

3. Methodology

The methodological procedures used in previous studies associating night lights with urban settlements for the US had to be adapted taking into consideration the unique patterns of urban settlement of the Brazilian Amazonia region. The main methodological concerns were related to DMSP/OLS image processing, described in Section 3.2. A new threshold value must be chosen to classify each pixel as lighted or not, creating a binary image. The night-time light foci were converted to a polygon vector representation in order to enable a spatial query associating the foci, with village and downtown city centres.

The first procedure was building a spatial database for the Amazonia region. The geographical information system—SPRING, version 3.5 (Câmara, Souza, Freitas, & Garrido, 1996) supported this spatial database and made it possible to carry out all the analytical procedures, including the digital image processing and data integration, described in the following sections.

3.1. Database description

The database was comprised of three different data sources: DMSP/OLS, JERS, and Landsat TM remote sensing imagery; census data; and electrical power consumption data. Every data presented in the database were converted to the Polyconic Projection and concerned to the Amazonia region limits (from 47°W to 41°W of Longitude, and from 8°N to 20°S of Latitude). JERS and Landsat TM images were available in an ancillary geocoded database, named "*Mosaico do Brasil*" (http://www.dpi.inpe.br/mosaico). The main source of information was the colour compositions of bands 3(B), 4(G) and 5(R) Landsat TM from 1998 and 1999, available as a 120 m spatial resolution mosaic. A JERS radar image was useful to observe regions of frequent cloud cover where no data were available from Landsat TM mosaics. Differences in spatial resolution enable checking the correspondence between the night light foci (obtained from a 1 km pixel resolution—DMSP) and the respective land cover class (observed at 120 m pixel resolution—Landsat TM mosaic).

Rural, urban, and total population counts were selected from the 1996 census. Municipal boundaries and the latitude and longitude of municipal and village centres were also obtained from the census database. All the boundaries and urban central coordinates of the 749 *municípios*, [3] as well as the geographical positions of the 256 villages were georeferenced. Population estimates for villages and urban centres that had not been included in the official census data were also obtained from municipal governments in order to compare urban population estimates obtained from the linear regression.

The electrical power consumption data were obtained from the power companies of the states of Acre, Amapá, Amazonas, Pará, and Rondônia (80% of the region). The data set included total electrical power consumption, measured in kWh for 1999, and grouped according to the different activity sectors: residential, industrial, commercial, rural, public illumination, and public services.

3.2. DMSP/OLS image processing for night-time light foci extraction

A stable night-time light image mosaic covering Brazilian Amazonia was used. The mosaic was generated by NOAA—National Geophysical Data Center, from 16 single DMSP/OLS orbits, from September 2nd to 18th, 1999. Night-time passes of the DMSP typically occurred between 8:30 p.m. and 9:30 p.m. local time. To get only stable light sources in the final image, ephemeral night-time light like clouds and fires were removed during the mosaic process, using the procedure described by Elvidge et al. (1997a). The original image data were available in an Equidistant Cylindrical projection. Its cells were 0.008333 degrees square, or 1 km^2 approximately. The conversion to Polyconic projection was the only geometrical correction applied to

[3] In Brazil, each state is divided into *municípios*—a territorial area, governed by a mayor, that includes a main city, a rural area, and small settlements and villages.

the image. Although the DMSP/OLS image used an 8-bits quantization (256 values), its histogram has only frequencies up to 100, related to the percentage of lighted pixels. This way, digital numbers in the image represent the cumulative percentage of lighted pixels, considering the available night-time cloud screen orbits, and not the reflectance values.

The next step was to select a threshold for the pixel values that would be able to identify urban areas without overestimating larger cities or underestimating small villages. The binary images obtained by applying different threshold values were comparable to the DMSP/OLS data, using the location of small towns and big cities in the Landsat TM image as a reference. To preserve the city boundaries and to detect small towns for the continental US, Imhoff et al. (1997) have used a threshold value of 89%. In this study, a threshold of 7% overestimates the city boundaries, and a threshold of 89% does not detect most of the small towns. So, a threshold of 30% was fixed to generate a DMSP binary image with two values, one assigned to the classes of background and other to lighted pixels. Thus, the image was converted into boundaries, extracting polygons of night-time light area, hereafter called night-time light foci. As a result, the image and boundary (polygons) representations of the night-time light areas were available in the database.

3.3. Data integration and analysis

The process of data integration and analysis is depicted in Fig. 1. First, to identify the relation of DMSP/OLS data with urban settlements and human activity in Amazonia, the boundaries of the night-time light foci were compared with the geographical coordinates of IBGE urban centres and villages. Using spatial query tools, the *municípios* that did not contain any night-time light foci were retrieved. Similarly, all the night light foci that were less than 5 km from urban centres and

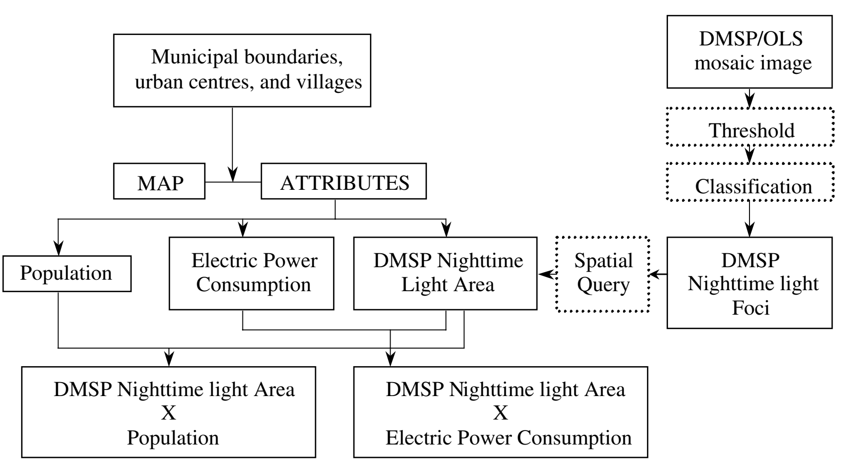

Fig. 1. General methodology—data integration and analysis flow-chart.

villages were obtained. Then, all the night-time light foci that do not correspond to any IBGE data were reviewed on the auxiliary image data (Landsat and JERS): the geographical coordinates of the foci were identified using a higher spatial resolution imagery and the land cover/land use class noticed. This procedure identified all the human activities detected by DMSP night-time lights which were unrelated to census data (position of urban centres and villages).

Linear regressions were applied to explore the relations between DMSP/OLS night-time light and the human population, and between DMSP/OLS night-time light and electrical power consumption.

4. Results

4.1. Relationship between DMSP/OLS night-time lights and human activity/urban sites in Amazonia

The capability of the DMSP/OLS data to detect human activity was checked overlaying the DMSP night-time light foci with the city centres and *villages*. Using a threshold higher than 30%, it was possible to identify 261 night-time light foci. Visually, it was noticed that the night-time light foci and the spatial representation of the IBGE urban centres match, as presented in Fig. 2.

From a total of 261 night-time light foci, 149 contained IBGE urban centres, 64 were less than 5 km from IBGE urban centres and 48 night-time light foci were not related to any urban centre. These were analysed using the ancillary data from "*Mosaico do Brasil*" and indicated that DMSP night-time light detection was closely related to human activity (Table 1). Even in places with no resident population, the lights indicate human presence that requires some type of infrastructure, such as mining or gas production.

A total of 749 *municípios* analysed within the state boundaries of Amazonia, 186 were found inside the night-time light foci and 62 were less than 5 km from the foci, totalling up 248 cities noticed by the DMSP/OLS data. Only 30% of the *municípios* were registered by DMSP night-time lights due to the DSMP image temporal mosaic characteristics: only 10 days of September were used to register stable night lights in a very cloudy region, in the burning season, in 1.1 km of spatial resolution. Despite these restrictions and considering the total resident population, there was night-time light from *municípios* with population up to 2000 inhabitants. All the *municípios* with population higher than 100,000 residents were detected. Others, with population lower than 100 thousand inhabitants, were not detected. DMSP night-time light were not registered for 501 *municípios*. Table 2 illustrate these results. For example, Santa Luzia do Maranhão was an undetected *município*. It has the largest total population (of 19,450 were urban population in a total of 53,287); the lack of Landsat TM images and mosaics between 1999 and 1997 from this area could indicate a frequent cloud cover. Alta Floresta (MT) had the largest urban population (35,053 people), and it was detected only with the DMSP image threshold higher than 7%. Probably it is due to very intense fires and smoke in this region when the satellite sensor images

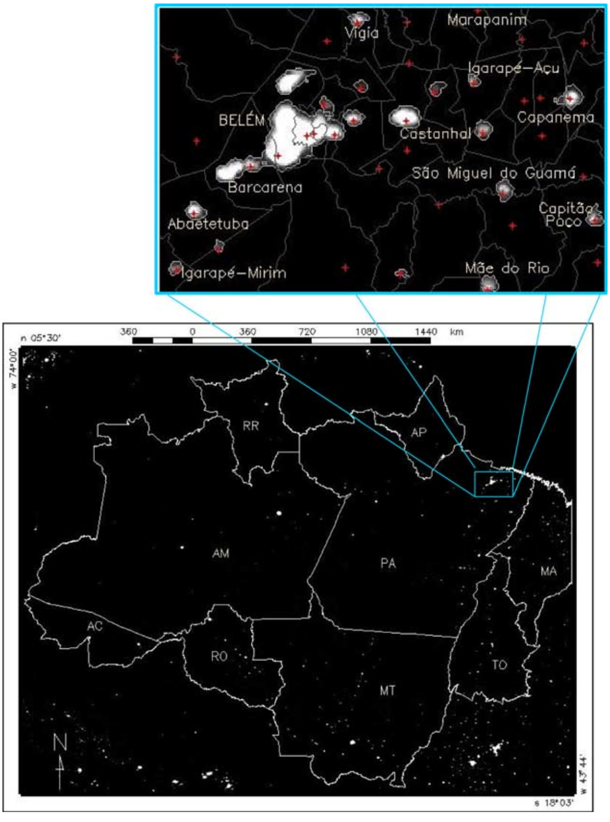

Fig. 2. DMSP/OLS night-time light image over Amazonia. In detail: Belém metropolitan region, state of Pará.

Table 1
DMSP night-time light foci not associated with urban centres

Description—targets observed in "Mosaico do Brasil"	No. of DMSP foci
Urban settlements—small towns and villages—missing in IBGE census	9
IBGE villages	3
Urban nuclei near big cities	4
Villages near reservoirs	2
Mining	3
Oil and gas production (URUCU-AM)	1
IBGE urban centres—inaccurate coordinates	16
Unable to check—Landsat TM or JERS images not available	7
Outside of Amazonia limits	3

were taken, attenuating the night-time light signal. Only 25 of the 501 undetected towns had urban populations greater than 10,000 inhabitants. With the exception of Alta Floresta and Rosário do Oeste, both located in the state of Mato Grosso, all of

Table 2
Frequency of *municípios* in the Amazonia region for each class of population

Total population (IBGE, 1996)	Number of *municípios*	
	Total	Detected by DMSP
0–2000	32	1
2000–5000	133	5
5000–10,000	180	28
10,000–20,000	206	67
20,000–50,000	145	96
50,000–100,000	36	34
100,000–200,000	7	7
200,000–500,000	7	7
500,000–1,000,000	1	1
>1,000,000	2	2
Total	749	248

them were in the northern of the states of Acre, Amapá, Pará, and Maranhão. In these areas cloud cover is very frequent.

Among the 248 towns detected by DMSP night-time light, Paço do Lumiar (MA) presented the smallest urban population (1095), but it is adjacent to São José do Ribamar and São Luís, the capital of the state of Maranhão. So it is part of a metropolitan region. The city detected by DMSP night-time light with the smallest urban population was Alto Alegre (RR), with 3292 people within the urban limits.

4.2. Relations between DMSP/OLS night-time lights and urban population estimates

In Amazonia, 60% of the population lives in urban areas, and the DMSP/OLS data register night-time light in a spatial resolution of 1 km^2. Therefore the comparison of DMSP/OLS night-time light and population was restricted to the urban population data.

For the *municípios* in Amazonia region, the population was plotted (Fig. 3). Note that the dispersion of the DMSP night-time light area for *municípios* with population less than 250,000 inhabitants, and the saturation of the DMSP night-time light area for *municípios* with urban population higher than 400,000 inhabitants were observed. The saturation of the DMSP night-time light area can be explained by the human concentration in urban centres. They are observed in cities with more than 400,000 people, and such concentration is due to the dense vertical occupation process. These cities correspond to the capital of the states of Amazonia.

To assess accuracy and to reduce variability and heterogeneity, data analysis was restricted to the state of Pará. Pará has 1,249,460 km^2 and it is a representative sample since it comprises approximately 25% of the Amazonia region, and it has complex land use such as deforestation, mining, timber exploration, forest reserves, conservation units, agriculture, pasture, urban areas, etc. A number of 54 *municípios* had its night-time lights detected by DMSP imagery in a total of 142 *municípios*. The relation between urban population and DMSP night-time light area is presented in

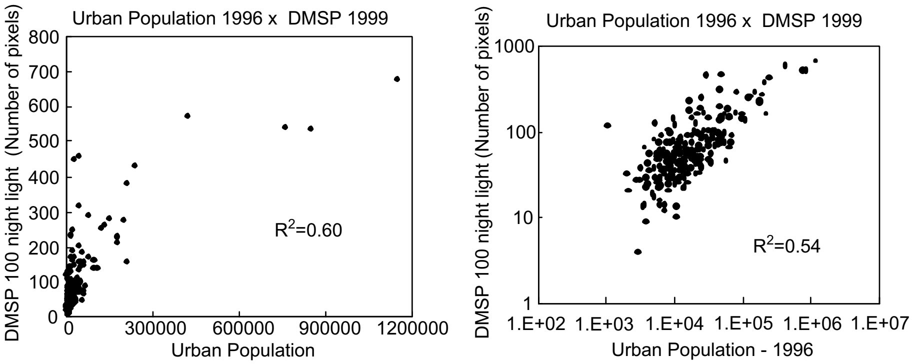

Fig. 3. DMSP night-time light area for 1999 plotted against the urban population (1996) for all the *municípios* in the Amazonia region.

Fig. 4, excluding the city of Belém—the capital of the state with more than 1,000,000 people. Although many values of DMSP night-time light are not linearly related to urban population, by examining the Landsat TM images, they can be recognized as *municípios* with additional economic activities (exploration mining, for example), which requires illumination 24 h per day or since they are *municípios* in the metropolitan area where the intense lighting from the capital Belém is accounted for the neighbour *municípios*. Hence, these *municípios* were discarded from the data set, and a linear relation can be observed between urban population and DMSP night-time light area for the state of Pará (Fig. 5) with a coefficient of determination (R^2) equal to 0.79. This result is compatible with that obtained by Elvidge et al. (1997b), ($R^2 = 0.85$) in a log–log relation of population and DMSP light area, considering 21 countries on a global scale.

The linear regression model was used to estimate the population of other urban sites detected by the DMSP night-time light in the Amazonia region, whose

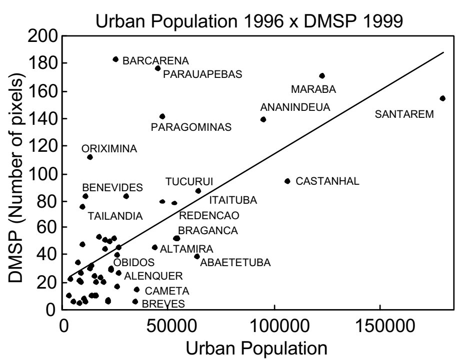

Fig. 4. DMSP night-time light area plotted against the urban population (IBGE, 1996) for *municípios* of the state of Pará, excluding Belém, the capital.

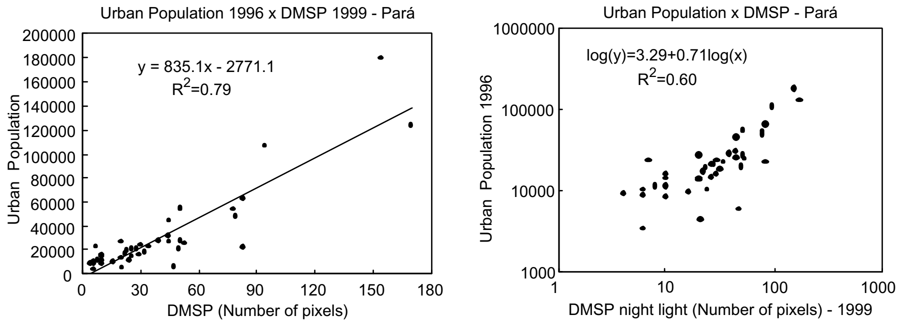

Fig. 5. Linear relation between DMSP night-time light area and the urban population for *municípios* of the state of Pará.

Table 3
Urban population estimated by the linear relation with DMSP night-time light and obtained through field information

Site—State	Urban population	
	Estimated	Observed
Lourenço—Amapá	1100	1203
Mosqueiro—Pará	72,388	34,808
Parauapebas—Pará		
Urban centre	48,690	45,649
Village	70,000	81,260
Oriximiná—Pará		
Urban centre	23,638	23,540
Village	26,979	6500
Tucuruí—Pará	16,123	14,000

population values were unavailable in the IBGE 1996 census (IBGE, 1997). The urban population estimated by the regression was compared to estimates provided by the mayor's office of the respective *município*. Some results are presented in Table 3, and important noteworthy cases are described below.

A population of 72,388 was estimated for the village of Mosqueiro, in the state of Pará, using the regression model. However, since Mosqueiro is on the river edge, the DMSP sensor captured the light reflected by the river, producing a situation referred as the "blooming" effect (see Fig. 6). To correct this effect, half value of DMSP night-lights for Mosqueiro was used to estimate its population. With this correction, the estimates decrease to 34,800 inhabitants, which is coherent with the field information (approximately 30 thousand inhabitant).

For the *município* of Parauapebas, in the state of Pará, the total of DMSP night-time light area estimated a population of 144,200 people, but this value was related to three night-time light foci (illustrated in Fig. 7):

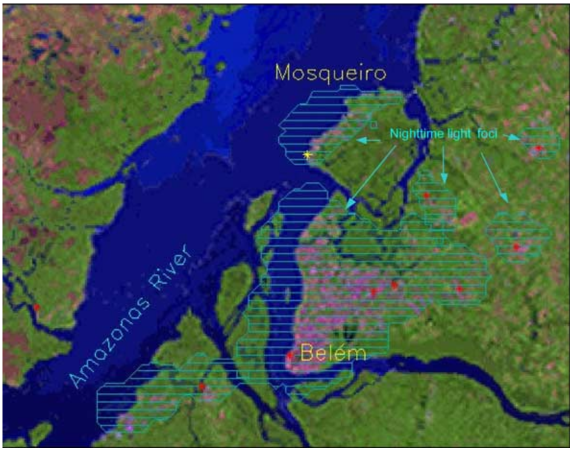

Fig. 6. The "blooming" effect of DMSP night-time light at Mosqueiro/Belém region. Polygons of night-time light foci over Landsat TM colour composition image.

(1) The night-time light focus estimated 48,690 people for the urban area within the city limits and it was 45,649 people;
(2) The night-time light focus estimated 81,260 people for the village of *Serra dos Carajás* (an iron mine). The village was built to support 70,000 people. Even though the mining region is illuminated 24 h a day, there are no permanent residents;
(3) The night-time light focus estimated 6939 people for the gold mining area, but there are no permanent residents at the mine.

For the village of Tucuruí, in the state of Pará, the regression estimated 16,123 people. The field data revealed 14,000 people living in the village, while some adjacent civil construction activities require very powerful illumination. This may have contributed to an overestimation based on DMSP night-time light.

These results suggested that the linear regression was a reasonable model to estimate population based on DMSP night-time light, even using data from a region—the state of Pará, and applying it to the whole Amazonia region. Some particular night-time light foci must be dealt separately, like the urban areas along the river edge and the activities that demand intense illumination such as the mining and civil construction detected in this study.

DMSP night-time light foci have also the potential use as a reference of human activity and urban settlement as assumed variables in land use and land cover change (LUCC) models. Many LUCC dynamic models are based on regression models involving data aggregated by *municípios* (e.g. Andersen & Reis, 1997; De Koning, Veldkamp, Verburg, Kok, & Bergsma, 1998). Due to disproportionate size of Amazonian *municípios* as compared to their respective cities, projective models need to have the city limits and urban population correctly defined and spatially represented. Night-time light maps can provide a valuable tool for this modelling process.

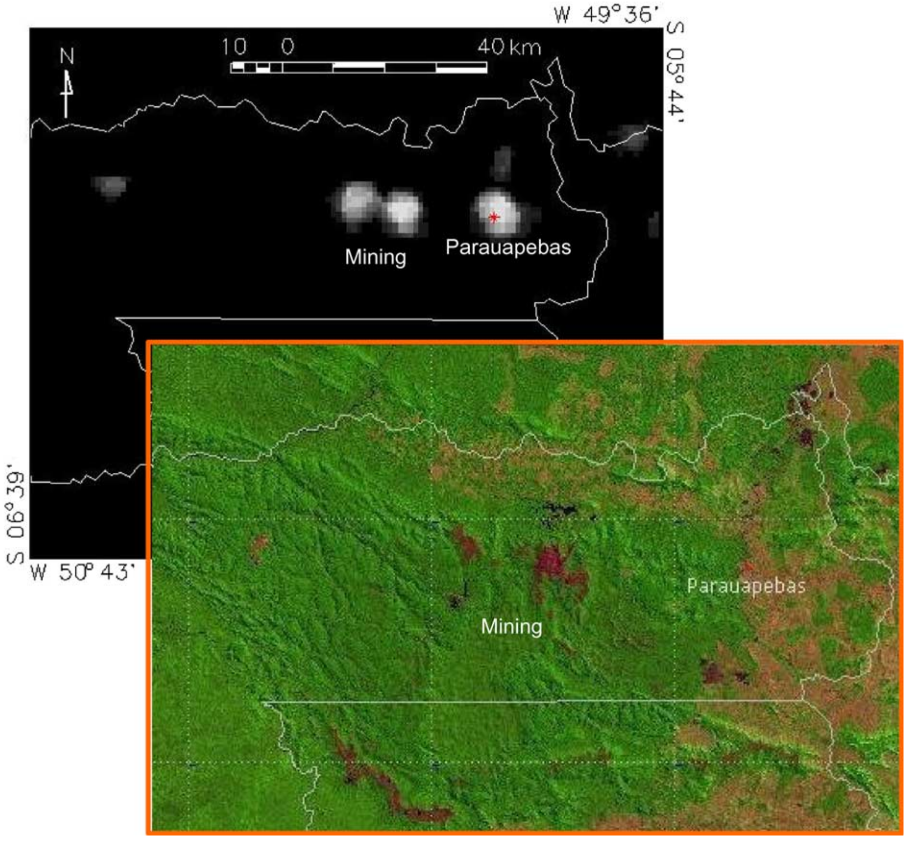

Fig. 7. DMSP night-time light and Landsat TM colour composition images related to *município* of Parauapebas, state of Pará.

4.3. Relations between DMSP/OLS night-time lights and electrical power consumption

The relations between the DMSP night-time light areas and electrical power consumption for the state of Pará were also studied (Fig. 8). Electrical power consumption data were obtained from the state's power company, according to consumer type (residential, industrial, commercial, rural, public illumination, and public services). A linear relation ($R^2 = 0.91$) was obtained relating population and non-industrial electric power consumption.

Thus, it was conjectured that the DMSP night-time light was related to non-industrial lights such as public illumination, roads, external lights of houses, parking lots, and shopping center lighting. To check this assumption, the relation between the DMSP night-time light area and the electrical power consumption for public illumination and commerce was determined (Fig. 9). Residential electrical power consumption was excluded from this analysis since the external use of electricity for houses is negligible when it is compared to public illumination and commercial use.

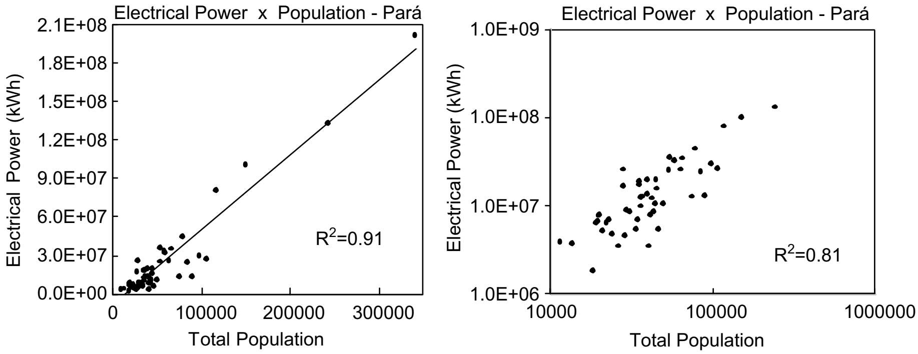

Fig. 8. Electrical power consumption for 1999 (kWh) and total population (1996) for all *municípios* of the state of Pará, excluding Belém, the capital.

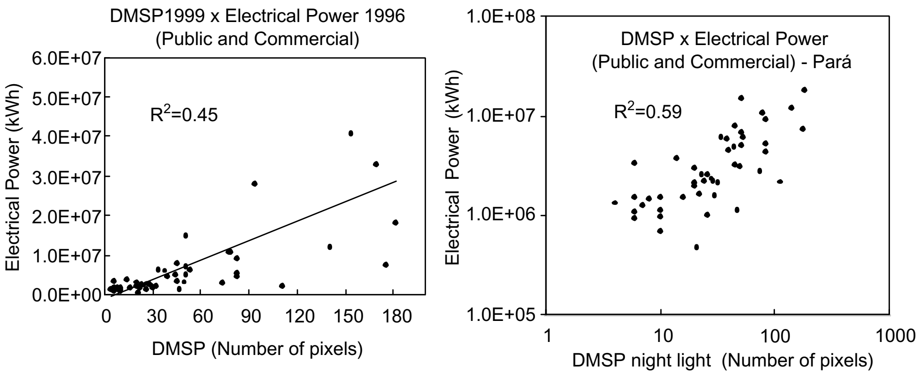

Fig. 9. DMSP night-time light area and the electrical power consumption for public and commercial sectors at 1999 (kWh) for all the *municípios* of the state of Pará, excluding Belém, the capital.

At first glance, the relation between DMSP and electrical power consumption showed a high dispersion, mainly for those *municípios* with DMSP night-time light areas higher than 100 pixels. As mentioned in the previous section, some *municípios* have special characteristics and in this sense, they were discarded from the data set. After this procedure, a linear relation between the electrical power consumption (public + commercial illumination) and the night-time light pixels of DMSP imagery was observed, as shown in Fig. 10 ($R^2 = 0.80$). Similarly, the total electrical power consumption can also be estimated from the DMSP night-time light (see Fig. 11), with $R^2 = 0.79$. This result is coherent with Elvidge et al. (1997b). They obtained a coefficient of determination of 0.96 for relating electrical power consumption and DMSP light area of 21 sampled countries in a less detailed scale data, than municipal one. Additionally, Sutton et al. (1997) in a similar study between the DMSP area and urban clusters for the continental US, obtained

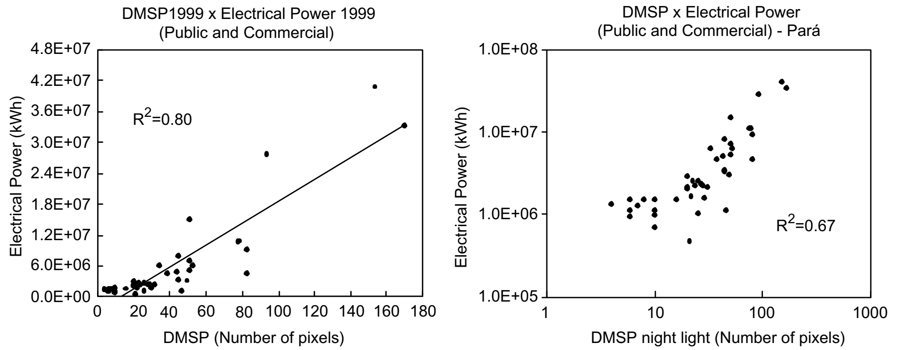

Fig. 10. DMSP night-time light area and the electrical power consumption for public and commercial sectors at 1999 (kWh) for the state of Pará.

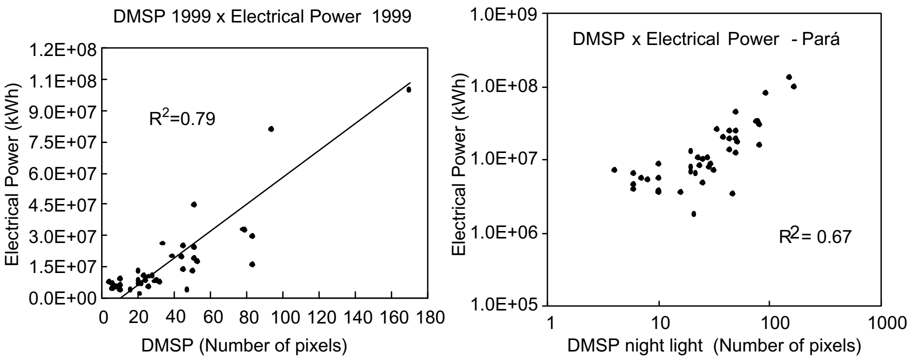

Fig. 11. DMSP night-time light area and the total electrical power consumption (kWh)—1999 for the state of Pará.

statistically significant results in linear ($R^2 = 0.84$) and in exponential ($R^2 = 0.93$) regression models. The differences between the results in the literature and in this study can be attributed to the substantial economic and social differences between Brazilian and American urban settlements. In US, they have more equipment, better infrastructure, and, consequently, more lights than the Amazonia region.

Although the substantial differences in Amazonia urban settlements and other regions around the globe, the establishment of a positive relationship between DMSP and urban population and between DMSP data and power consumption in the region can be considered as important results. It should be noted that this result was obtained after a critical analysis of DMSP data and the removal of influential values effects and particular night-time light foci.

5. Conclusions

This work explores the DMSP/OLS night-time light imagery as a potential indicator of human presence and activity in the Amazonia region. The results indicated that DMSP night-time light data are a consistent indicator of human activity in Amazonia. The imagery data available enabled the identification of all urban centres with more than 50,000 inhabitants. The constant cloud cover, the small size of the urban nuclei, and problems in the electrical power supply throughout the Amazonia region prevented a detailed estimation of urban settlements smaller than 50,000 inhabitants. Moreover, there is a linear relation between DMSP and population and DMSP and electrical power consumption. However, it is indispensable to identify *municípios* that have additional economic activities (mining exploration, for example), or *municípios* in the metropolitan area, and discard them from the original data set. These restrictions are also applied when DMSP is used to estimate population and/or electrical consumption for regions with similar socio-economic and spatial patterns.

Any projective/predictive model of settlement process in Amazonia must take human activity into account. Better public services and infrastructure for urban and rural population within the urbanization process have been positively linked to a decreased pressure on the frontier due to reduced rates of deforestation (Becker, 1998). The speed and dynamics of change in land cover in the region, the lack of more frequent census data, and all the strategic infrastructure programs proposed by the federal government for the Amazonia region (Governo Federal, 2000), assign DMSP data as an important reference of human activity in future analysis of spatial–temporal patterns in Amazonia.

The results from this study suggest that public policy makers may refer to DMSP data as a valid indicator of actual human socio-economic activity in the Amazonia region as long as the necessary statistical constraints are applied.

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