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Influence of the Solar Power Plant on the Diversity of Mammals: A Case Study in Northeastern Brazil

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Abstract: Despite producing clean and renewable energy, large solar projects can affect wildlife due mainly to habitat loss and land use. Therefore, the goal of this study was to evaluate the influences of the Solar Power Plant Ituverava on the local mastofauna. The study area contained three samples called Zone 1 (Z1) — called Legal Reserve and Green Belt (category IV, IUCN); Zone 2 (Z2) — Control area with native vegetation; and Zone 3 (Z3) — project intervention area. We recorded 991 contacts with medium and large mammals belonging to 37 species and seven mammalian orders. The analyzes do not indicate significant differences in the diversity of mammals between the areas, suggesting that the mastofauna in the region is using different environments, including in the areas of solar panels (Z3). Some species, including two threatened with extinction, had a more significant number of records in Zone 3. Fauna passages projected below the company's fences associated with the presence of food, refuge, and shelter in solar panels area appear to be establishing new niches now being occupied by some species, including endangered species.

Key words: energy sources, conservation, endangered species, wildlife management, solar power plant, Bahia

1. Introduction

Solar energy offers solutions to environmental problems related to the consumption of other more polluting energy sources, such as nuclear and fossil fuels [1]. This solar source can provide direct energy for lighting, heating fluids, or room fluids [2]. Also, through the conversion mechanism, it can generate mechanical and thermal potential, in addition to creating electrical energy through the induction of materials by photovoltaic panels [2]. Solar Energy Technologies (SET's) in this context present themselves as an inexhaustible source of energy, with low CO2 emissions, and small waste generation [3]. All these characteristics of solar energy sources provide numerous advantages for the sustainable development of human activities in the face of the current scenario of global climate change [3].

In South America, particularly in Brazil, SET's show enormous potential for development, since this country has one of the highest solar radiation rates worldwide [2]. Despite this, SET's still has little representation in its energy matrix, corresponding to only 1% (3.4 GW) of all installed capacity, according to the National Electric Energy Agency (ANEEL) [4].

The Brazilian territory is relatively close to the Equator, producing large amounts of radiation throughout the day and almost all year round [5]. The annual values of the global solar radiation incident in Brazil can vary between 1,550 and 2,400 kWh/m² [2,6]. This universal radiation values in Brazil are higher than the values of installed capacity in countries like Germany (900-1,250 kWh/m²) and France (900-1,650

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kWh/m²) [2, 6]. Even the Brazilian regions with the lowest radiation rates have a high potential for energy use, being comparable to the areas with the highest radiation in Germany [7].

However, the environmental impacts resulting from the implementation and operation of crucial solar energy projects have not been well investigated [7, 8]. Some studies already published show that the central damage to wildlife is related to land use [7]. The developed infrastructure and fences to restrict human access can lead to habitat loss, restriction of natural fauna movement, and migratory movements [7, 8]. In some cases, there are reports of mortality in populations of insects, birds, and bats due to collisions, electrocutions, and burns with equipment to produce solar energy [9]. Additionally, non-flying animals are affected only by being run over [8, 9]. In this connection, the magnitude of the impact generated by the production of solar energy can positively relate to the size of the project area [8]. This disturbance can also be positively associated with conservation and wealth in the surrounding areas, in addition to its proximity to natural areas, notably forest areas [8].

Other impacts on native fauna include noise emission, generation of electromagnetic fields, and changes in the microclimate [8]. Also, of note is the decrease in water availability and light pollution, including polarized light [7, 8]. However, studies carried out to date point out that environmental impacts are limited only to the areas of these projects [8]. There is no clear basis that the effects generated will cause significant changes in ecosystems on a larger scale. Notwithstanding, there are reports that some species have been affected in certain specific cases [7, 8].

In this perspective, the present study aimed to evaluate the direct and indirect influences of the Ituverava Solar Complex in the maintenance of mammal species in its insertion region, located in the city of Tabocas do Brejo Velho, Northeast Brazil. An inventory of medium and large-sized mammal was carried out in a transitional landscape to understand better which species persist in this area after the construction of this solar complex. This procedure served to calculate the diversity of mammal species in the study area.

2. Material and Methods

2.1 Study Area

The Solar Complex Ituverava (also known as Solar Horizonte Park, Fig. 1) is in the municipality of Tabocas do Brejo Velho, in the state of Bahia, Brazil (12°35'57.12"S, 44°6'40.98"W). This solar park consists of about 330 thousand panels and can produce more than 220 GWh per year. The territorial area of this solar energy complex is 527 hectares, which occupies a transition zone between the Caatinga and Cerrado, two brazilian regional biomes.

2.2 Sample Design

Data collection had four quarterly campaigns during the first year of operation of the project (October 2017 to September 2018). In this survey, we carried two collection campaigns in the rainy season and two in the dry season (Fig. 1).

The study region was divided into three sample zones (ZA), according to the degree of influence of the solar park. The Legal Reserve and the Green Belt (Zone 1: Z1) contain a fragment of 302.5 ha, adjacent to the area directly affected. This area falls within the Category IV protected areas in the IUCN protected area management categories. The Control area (Zone 2: Z2), includes an area of native vegetation with 1,745 ha. This second area was concentrated at 2.5 km from the solar power complex and had no direct influence on it. The third area (Zone 3: Z3) is directly affected by the presence of the solar plant. It contains definitive structures of the solar complex, such as some accesses, solar panels, offices, and a substation.

2.3 Medium and Large-Sized Mammal Survey

Macrofauna specimens present near the Solar Power Plant Ituverava was carried out with the use of camera-traps and the useful search method [10]. These methods are highly recognized in studies based on medium and large mammals, in addition to being complementary to each other [10].

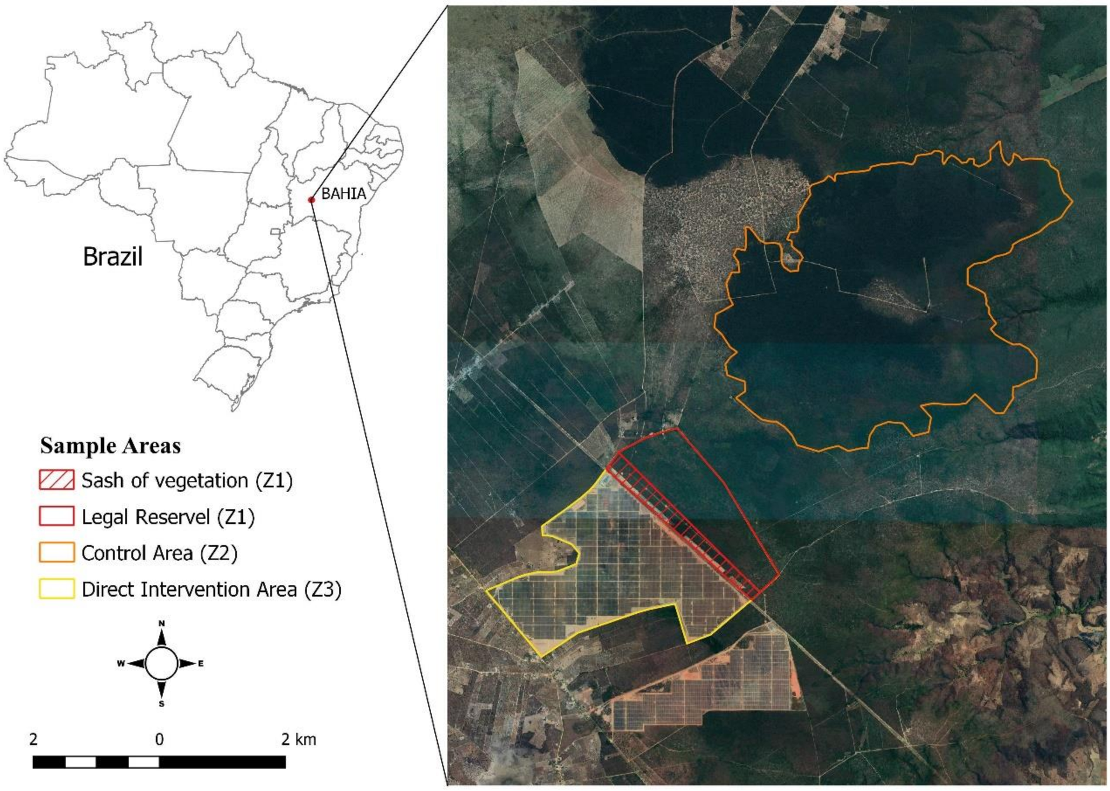

Fig. 1 Sampling points of the mastofauna and location of the Ituverava Solar Complex, Western Bahia, Brazil.

For the collection of experimental data, four-camera traps were installed in each sampling zone (Z1, Z2, and Z3), with Bushnell cameras, model 119719CW-24MP, from the Trophy Cam HD ® line. This type of camera can generate crisp, clear images with a super-fast shooting speed of 0.2 seconds, a recovery rate of 0.5 s, and a long nighttime interval. All equipment was kept in operation for 24 hours/day for five consecutive days. The total final sampling effort was 240 hours of monitoring the local mastofauna.

We used in the second research method the active search for direct or indirect evidence of species in the transects established in the sampled areas [11-14]. A 24-hour sampling effort was made in each zone. The total sampling effort corresponds to 72 hours of searching for the remains of mammal species present in the areas close to the Solar Power Plant Ituverava.

During field research, we looked for direct evidence of the presence of mammals as visual records and vocalizations. Additionally, we are also looking for other indications of the possible presence of these animals in the territory, such as trails, feces, burrows, carcasses, among others [12-19]. The identification of the evidence and the species observed was made with the help of specialized bibliographies [12-19]. Ultimately, the taxonomic arrangement of the species followed Paglia et al. [20].

2.4 Bats

For the sampling of the chiropterofauna (Mammalia) of the Solar Park of Ituverava, we opted to use the acoustic monitoring method and the species capture method through the fog nets. Six consecutive nights (from dusk to dawn) of acoustic monitoring in each established zone (Z1, Z2, and Z3), totaled about 72 hours of sampling effort.

This ultrasound detector (SM2BAT Passive Ultrasonic Bat Recorder, Wildlife Acoustics, Concord, USA) stayed for two nights in each sampling zone. During this period, the device remained connected to microphones that were positioned higher than the surrounding vegetation, or in open areas. Species identification by sonotypes followed the predictive classification of the discriminant analysis and the method of visualizing the sign designs [21].

Nine mist nets of about 9m in length were present in each area of the solar park (Z1, Z2, and Z3). These nets were kept armed from 6 pm to 11 pm, totaling 6,750 m^2*h, according to standardized effort [22].

After the collection of biometric data, these animals were marked with the appropriate ring and released at the end of the data collection at the same capture site. In this sample, there was no use of live traps. Thus, we may not have sampled all small individuals in the area satisfactorily.

Analysis of variance (ANOVA) and the Jaccard similarity index was performed to assess the influence of the solar park zones (Z1, Z2, and Z3) on the composition of the mastofauna. We also carry out investigations of the Shannon diversity index with the aid of package vegan and Project R for Statistical Computing version 3.3.2®.

3. Results and discussion

We recorded 991 contacts with medium and large mammals in the sampled areas. These animals belong to 37 species and seven Order of mammals. The cataloged Order of mammals are: Artiodactyla (01 sp); Carnivora (05 spp); Chiroptera (25 spp); Cingulata (03 spp); Lagomorpha (01 sp); Pilosa (01 sp), and Rodentia (01 sp) (Table 1).

Due to the non-sampling of small mammals, the number of species is undoubtedly higher than that observed. In Z1, there was a greater abundance of records, and in Z2, there was a higher species richness (Z2 s = 28 spp. / Z1 = 27 spp. / Z3 = 24 spp.). The Shannon-Weaver diversity index (H') varied little between the sampled areas (H' Z1 = 2.6 / H' Z2 = 2.6 / H' Z3 = 2.1). These results point to a smaller diversity in Zone 3. Nevertheless, the Analysis of Variance showed that the difference in Shannon's diversity values between the zones is not significant (ANOVA - $F = 0.03$; $df = 5.9$; $p = 0.96$).

Similarity analysis shows that the sample zones do not form distinct groups when considering the presence of species by zones during the data collection campaigns (Fig. 2).

All these analyses suggest that the region's mastofauna still do not prefer a specific sample area. This result remains unchanged even if we consider the most impacted area where the solar panels are present (Z3).

Our findings were not expected, since medium and large mammals tend to disappear from the site, or even decrease their populations due to the suppression of vegetation and consequent loss of habitat [23]. These species are more demanding in terms of habitat specificities and tend to be more susceptible to population decline, limiting their occurrence to less altered environments [23].

Some species cataloged in this study, such as deer (*Mazama* sp.) and felines (*Leopardus* spp.), had a higher occurrence in Z1 and Z2, which are areas of native vegetation. These species have a discreet behavior and are adapted to exploit resources inside the vegetation, presenting low occurrence in altered areas such as Z3 [24, 25].

In contrast, some species, including endangered species, were commonly observed foraging between solar panels, such as the hoary fox (*Lycalopex vetulus*) and the maned wolf (*Chrysocyon brachyurus*). The hoary fox weaves 68% (N = 22) of the records in Z3, while the maned wolf had 75% (N = 4) of sightings in Z3 (Fig. 4).

Despite belonging to the mammalian order Carnivora, these canids have a very varied diet and adapt to open areas in regeneration, in addition to clearings and forest edges [18]. Thus, some factors may have contributed directly or indirectly to the persistence of *L. vetulus* and *C. brachyurus* in the areas of intervention of the enterprise (Z3). The ecological characteristics and fauna passages located below the fences of the enterprise may explain these findings. Probably, the planning of passages allowed the flow of individuals through the landscape and natural fragments. The prohibition of hunting and the restriction of access to the area by human beings can also be agents that will lead to the results obtained. Lastly, we can also remark about the provision of places to feed and house these animals.

Table 1 Mastofauna diversity sampled at the Solar Power Plant Ituverava, Western Bahia, Brazil. Legends: Z1 = Legal Reserve and Green Belt, Z2 = Control Area, Z3 = Intervention Area.

Mammal Orders	Species	Sampled Areas		
		Z1	Z3	Z2
Artiodactyla	Mazama gouazoubira	1	-	3
Carnivora	Chrysocyon brachyurus	-	3	1
	Eira barbara	-	-	3
	Leopardus pardalis	1	-	1
	Leopardus tigrinus	3	2	3
	Lycalopex vetulus	2	15	5
Chiroptera	Artibeus lituratus	-	1	2
	Artibeus planirostris	1	1	-
	Carollia perspicillata	10	3	28
	Centronycteris maximiliani	110	83	59
	Cynomops greenhalli	42	89	24
	Eptesicus furinalis	-	3	4
	Eumops glaucinus	3	-	-
	Glossophaga soricina	7	2	9
	Lasiurus cinereus	38	24	7
	Molossops temminckii	16	2	10
	Molossus molossus	5	9	-
	Molossus rufus	9	21	3
	Mycronycteris sanborni	2	-	-
	Myotis nigricans	23	3	6
	Nyctinomops macrotis	31	12	9
	Peropteryx kappleri	2	-	8
	Phyllostomus discolor	2	-	-
	Phyllostomus hastatus	3	1	-
	Platyrrhinus lineatus	-	1	-
	Pteronotus gymnonotus	15	-	1
	Pteronotus parnellii	5	-	1
	Pteronotus personatus	46	17	15
	Sonotipo 1	43	3	3
	Sonotipo 2	54	2	4
	Sturnira lilium	1	-	-
Cingulata	Cabassous unicinctus	-	-	1
	Dasypus novemcinctus	1	1	1
	Euphractus sexcinctus	-	1	1
Lagomorpha	Sylvilagus brasiliensis	-	-	1
Pilosa	Tamandua tetradactyla	-	1	-
Rodentia	Dasyprocta prymnolopha	-	-	2
TOTAL	-	476	300	215

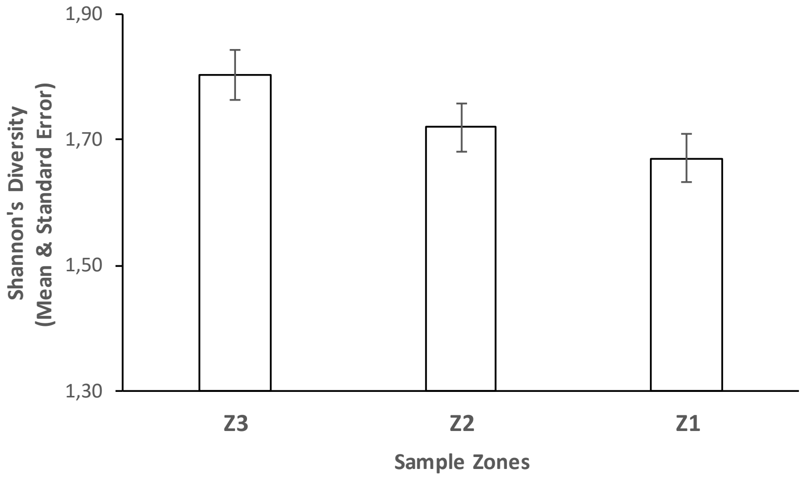

Fig. 2 Shannon's diversity between areas after the first year of operation of the project (mean and standard error).

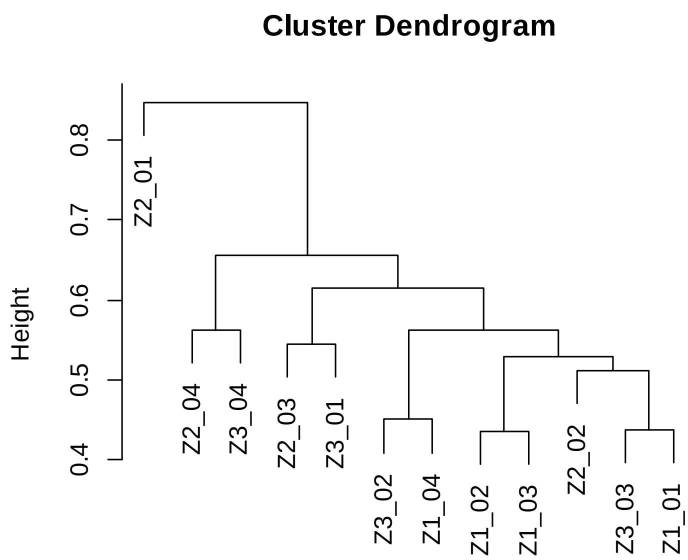

Fig. 3 A cluster analysis of the sampled areas during the execution of the campaigns (numbers 01 to 04).

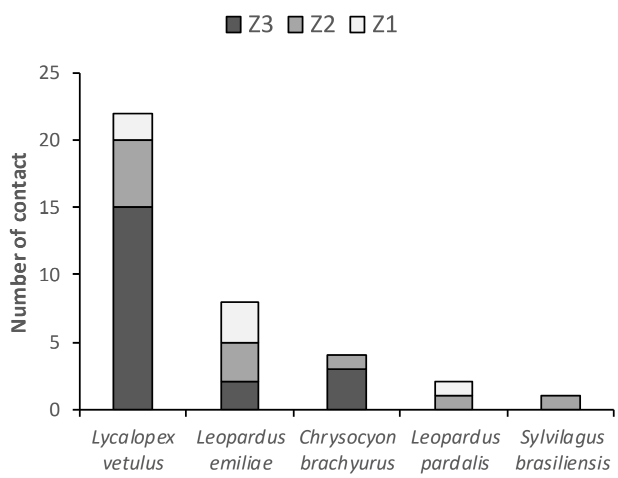

Fig. 4 Total records of threatened mammal species after the first year of operation of the Solar Power Plant Ituverava, Tabocas do Brejo, Northeastern Brazil.

According to some studies, fruits of pioneer species, in addition to insects, rodents, and armadillos are the main food items consumed by *L. vetulus* and C. *brachyurus* [25, 26, 18]. In Z3, *Solanum crinitum* — "Lobeira da Mata" and small rodents (*Cavia aperea, Rhipidomys macrurus, and Wiedomys pyrrhorhinos*) adapted to the underground electrical cable ducts. We can also mention some species of armadillos such as *Cabassous unicinctus, Dasypus novemcinctus, Dasypus emcinctus, and Euphractus sexcinctus* that are present in this same area [24].

L. vetulus is known as an omnivorous species associated with the sub-shrub stratum of the Cerrado Biome [26, 27]. Dal-Ponte and Lima (1999) also showed that the fruits of the "Lobeira" (*Solanum lycocarpum*) constitute an essential food source for *L. vetulus* throughout the year, especially during the dry season [26]. Other fruits are part of this animal's diet, as well as insects and small vertebrates [26].

Likewise, the C. *brachyurus* diet consists of 60% fruits and 40% small vertebrates [27]. Many studies agree that the fruit of *S. lycocarpum* is the main food item consumed by the maned wolf [26, 27]. In the Solar Power Plant Ituverava, the "Lobeira" grows between the solar modules amid the regrowth of vegetation. This vegetation associated with a large area with restricted access to humans and hunting prohibition seems to be providing ideal feeding and shelter sites for these animals.

The fauna passages located below the company fences allow the flow of individuals in the landscape. This access may not be allowing the total isolation of the populations after the installation of the enterprise (Fig. 5). In contrast, fences of large enterprises associated with their definitive structure generally affect daily fauna movements, migration and the survival of medium and large animals [28].

Fig. 5 An individual of *L. vetulus* crossing the fence of the green belt project to the areas of the solar panels.

This study is not yet conclusive and should be better understood with the continued monitoring of mastofauna in the Solar Complex Ituverava in the coming years. The risk of the barrier effect and the loss of habitat are the main threat to the fauna. These prerogatives should always be considered when developing large-scale solar energy projects. However, we clarify that the absence of significant differences in the values of the diversity of mammals in the sampled areas, and above all, the persistence of endangered species foraging between solar panels are essential discoveries [28, 29].

The development of this type of project has the potential to increase environmental degradation over a place on regional scales with consequent adverse effects on wildlife [8]. However, despite this potential environmental impact of the solar energy complex, studies to date indicate that the effects appear to be limited to the margins of these companies' areas [7, 8]. This type of enterprise on a regional scale does not necessarily affect the composition of the fauna [8]. There is still a scientific gap in this section, although some studies show species being affected by specific cases of such buildings.

In the three Zones (Z1, Z2, and Z3), the diversity values are very similar. We believe that the conservation of specially protected habitats (Zone Z1) around solar panels may be indirectly helping to maintain wildlife in that region. These results indicate that the operation of the Solar Power Plant Ituverava had its impacts reduced due to the preservation of essential areas combined with the restriction of human access and fauna passages.

The Ituverava case study suggests that the Legal Reserve and the Green Belt (Z1) may serve as areas that support local biodiversity. In this area, individuals may be moving to other sectors in the region, including areas where there are solar panels (Z3).

We assume that the polarotactic insects associated with the company's solar panels and lighting structures may favor the presence of mammals with an insectivorous diet in this region. Schnitzler and Kalko (2001) point out that mammals specialized in exploring biological resources in the canopy and within the vegetation must have a higher population representation [8, 30].

Finally, frugivores and nectarivores are probably acting in the process of restoring local ecological processes. These groups of animals must be dispersing seeds and pollinating pioneer species, such as Piper spp. (Piperaceae) and Solanum spp. (Solanaceae). The presence of these species in the recolonization of Zone Z3 (Area of Direct Intervention) confirms these findings.

4. Conclusion

After the first year of operation, the Solar Power Plant Ituverava does not seem to have a negative influence on the region to the point of affecting the diversity values and the composition of medium and large mammals and chiropterans. We can say that there is a dynamic of mastofauna between the three sampled zones.

Projects of this magnitude can change the local ecosystem, but, at the same time, establish new niches that can be exploited by some species. We can include in this context endangered species, as indicated by the presence of hoary fox and maned wolf in the areas of solar panels, where some individuals use them as a refuge.

As solar energy projects in Brazil are still recent, new studies, including in other plants, are needed to improve the understanding of the effects of the implementation and operation of these projects on biodiversity.

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