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Atlantic forest mammals cannot find cellphone coverage

Leandro Macedo[a], Carlos Henrique Salvador[a,*], Nadia Moschen[b], Adrian Monjeau[c]

[a] Laboratório de Ecologia e Conservação de Populações, Departamento de Ecologia, Universidade Federal do Rio de Janeiro, Rio de Janeiro, Brazil
[b] Instituto de Investigaciones en Diversidad Cultural y Procesos de Cambio, Universidad Nacional de Río Negro & CONICET, Bariloche, Argentina
[c] Departamento de Análisis de Sistemas Complejos, Fundación Bariloche & CONICET, Bariloche, Argentina

A R T I C L E I N F O

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A B S T R A C T

We present a novel and simpler way to measure human influence: the cellphone coverage. Besides, we also evaluated its influence in the probability of occurrence of medium and large wild mammals in Brazilian Atlantic Forest, as a study case. As a first step, we have demonstrated the correlation between cellphone coverage and human footprint globally, using a database of > 23 million antennas. Then, we have carefully studied the correspondence between the presence of a species and the cellphone coverage for 45 species of medium and large mammals of the Brazilian Atlantic Forest. We recorded 18,211 points of presence of mammals, and their probability of being under cellphone coverage was on average very low (18%). Most of the species showed a clear negative relationship with cellphone coverage, and threatened species presented an even lower probability, of at least 4% when compared with non-threatened ones. The strong positive relationship between cellphone coverage and the Human Footprint gradient at a global scale corroborated our *a priori* hypothesis that cellphone coverage can act as a surrogate for human presence, even in forested areas were no other footprint evidence is easily detectable.

1. Introduction

Indicators of human activities as a threat to biodiversity are important for monitoring wildlife and nature conservation planning. The Human Footprint (HFP), for example, is a map created by Sanderson et al. (2002) that measures human influence on terrestrial ecosystems. This index is formed by the overlapping of several global layers of information on factors of anthropogenic origin that have negative effects on ecosystems. They classified every biome of the world terrestrial surface into a score expressed as percentage of the relative intensity of land transformation, ranging from the most pristine (0) to the most transformed areas (100). Many studies have been using this type of information in their analyses (Di Marco et al., 2013; Toews et al., 2017), and two new and more updated versions were already proposed (WCS and CIESIN, 2005; Venter et al., 2016). On the other hand, in a recent paper, Ibisch et al. (2016) globally documented roadless areas, arguing that the impact of roads on surrounding landscapes goes far beyond the surface of the road itself, and they suggested that extensive areas without roads should be preserved. In this sense, roads can be interpreted as an indicator of human accessibility, but both Human Footprint index and roadless areas aim is to serve as a surrogate for human influence.

However, approaches like HFP and roadless areas does not consider cellphone coverage as a variable, which alone could be used as a modern and simple surrogate of human influence. It is in this sense that we have come to propose the cellphone coverage as a new indicator of human influence, representing its effects even when humans are absent. Similar to the increase in routes density, cellphone coverage expansion points to areas where human influence may be disturbingly increasing, and where focus in conservation should be more concentrated.

Acknowledging the degree of changes in the landscape is vital, since they have contributed greatly to defaunation (Bogoni et al., 2016; Ceballos et al., 2017) promoting both the decline of populations and the loss of species (Ceballos and Ehrlich, 2002; Galetti et al., 2017), particularly large mammals (Dirzo et al., 2014). This process of defaunation is so pronounced that a sixth mass extinction has been proposed (Barnosky et al., 2011; Ceballos et al., 2015; Kolbert, 2014), and the reduction of this biodiversity has favored the loss of ecological processes, which negatively affect the environmental services provided (Guimarães Jr. et al., 2008; Cardinale et al., 2012; Galetti et al., 2015).

In the face of changing environments, with increasingly human influence in natural habitats, the fauna has been facing a scenario of extirpations and sometimes, even extinctions (Canale et al., 2012; Ceballos et al., 2017). Therefore, besides from evaluating the usefulness of cellphone coverage as a simple proxy for human influence, we also evaluated its importance through a case study conducted with medium

* Corresponding author.
E-mail address: carlos.salvador@ufsc.br (C.H. Salvador).

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and large wild mammal species in a global hotspot for nature conservation, the Brazilian Atlantic Forest. Groups of animals with diverse threats of extinction degrees and niches, like large mammals in tropical forest, can provide a good study case to test if an enhance in human influence, using cellphone coverage as methodology, really do negatively affect biodiversity (Ceballos and Ehrlich, 2002; Dirzo et al., 2014; Galetti et al., 2017).

The Atlantic Forest is one of the most biodiverse biomes, and it is most affected by the advance on human influence, reason for which it has been included as a hotspot (Myers et al., 2000). This biome has been inhabited by humans through millennia, with different cycles and waves of human colonization (Dean, 2004) and extinction of fauna (MacFadden, 2006). Moreover, since not all species react in the same way to human pressure because their ecological traits differently influence the risk of extinction (Davidson et al., 2009), only few of the remaining patches are sufficiently adequate to house the most vulnerable species (Galetti et al., 2017). Here we focused on the Brazilian Atlantic Forest, which corresponds to 91% of its total occurrence (Olson et al., 2001), and was reduced to 12% of its original coverage, distributed in 245.000 forest remnants in several regeneration states (Ribeiro et al., 2009).

Thus, in this study we have two main goals. First, we wish to assess if cellphone coverage can be used as a proxy for human influence, comparing it to Human Footprint. Later, we aim to evaluate if medium and large sized wild mammals in the Brazilian Atlantic Forest respond to human influence, represented from this moment on by cellphone coverage.

2. Materials and methods

This study was divided into two steps, each of one in a different scale level. Firstly, we tried to assess if cellphone coverage is a good proxy for human influence, by collecting data of Human Footprint Index and cellphone towers from all over the world. Secondly, considering that the first test showed a good positive correlation, as expected, we conducted a more regional study case – in the Brazilian Atlantic Forest – taking medium and large-sized wild mammals as a test to evaluate how the wild life is behaving in areas under cellphone coverage. This study case was restricted to this biome once we were restrained to data availability and reliability, but this new proposed methodology should be able to show similar patterns in other parts of the world.

2.1. Human footprint and cellphone coverage

For the first step of our study, human influence data on the Earth's surface were based in the Human Footprint Indexes by WCS and CIESIN (2005) and Venter et al. (2016), where both utilize pixels of 1 km^2. These human footprint models were based on the method proposed by Sanderson et al. (2002), updating their databases. Venter et al. (2016) still showed a change over a temporal scale, with values ranging from 0 to 50, different from the 0–100 range previously used (Sanderson et al., 2002; WCS and CIESIN, 2005).

Regarding the cellphone coverage, we downloaded the global distribution from Base Transceiver Station through OpenCelliD's data bank (https://opencellid.org), which resulted in 23,637,215 positions (OpenCellID, 2016), collected from April 2008 to January 2017. The cellphone coverage then was obtained by converting these antennas into a polygon based on a pixel of 1 km^2, as recommended by GSM Association (GSMA). Therefore, we considered that each antenna has a coverage of 1 km^2.

We converted each point of information of cellphone towers into raster format with the same pixel size and projection as HFP's rasters using QGIS (Sherman et al., 2011). Therefore, we could count the number HFP's pixels under and outside of cellphone coverage. The probability of a HFP score to be under cellphone coverage was determined for each pixel using generalized linear model (GLM), with a binomial error distribution (Nelder and Wedderburn, 1972). To access the relationship between HFP and cellphone coverage, we calculated the coefficient of determination in logistic regression using the McFadden's pseudo R^2: 1-(log(likelihood of the fitted model)/log(likelihood of the null model)) (McFadden, 1973).

To better illustrate how this new proposed manner to assess human influence may supply with information which the Human Footprint Index may not be able to provide, we constructed a worldwide map, comparing these two methodologies (HFP × cellphone coverage). Also, we constructed a map comparing cellphone coverage and roadless areas, a more recent way to determine which areas are free from human influence, *i.e.* places with no roads, proposed by Ibisch et al. (2016).

2.2. Mammals and cellphone coverage

During 2012–2016, we conducted a broad review that gathered presence records of 45 species of medium and large sized wild mammals (> 1 kg) within the Brazilian Atlantic Forest. For that, we thoroughly searched in libraries and in internet bases such as Google, Google Scholar, Web of Science and Scopus, for data in scientific articles, and in the so-called gray literature, which includes monographs, dissertations, theses, congresses abstracts and technical papers (Tables A1 and A2). In addition, we also looked for museum records, personal sightings, as well as databases like the Portal da Biodiversidade (https://portaldabiodiversidade.icmbio.gov.br/portal/), and the Urubu System (http://cbee.ufla.br/portal/sistema_urubu/) which is composed of roadkill records for vertebrates. We limited the search to the Brazilian part of the Atlantic Forest, even if mixed with other biomes, based on Olson and Dinerstein (1998) and Olson et al. (2001) (Fig. 1), and with political borders delimited by the World Administrative Division (ESRI, 2016). We localized 811 Brazilian protected areas, considering IUCN categories I–V (IUCN and UNEP-WCMC, 2017) in order to check for cellphone towers inside of them.

The taxonomic classification followed Wilson and Reeder (2005), and the species' conservation status was based on the Brazilian official Red List (MMA, 2014). Here, we opted to use a national conservation status list, rather than a global one, because it gets closer to the real species´ status in the biome chosen as our study case. *Panthera onca*, for example, is considered by the national list as Vulnerable, *i.e.* more threatened status than the one considered by IUCN, which classified it as Near Threatened. Besides, we grouped species as Not Threatened or Threatened. The first group means the categories Data Deficient, Least Concern and Near Threatened, and the second species classified as Vulnerable, Endangered and Critically Endangered.

In order to guarantee the quality of the information acquired, all searches were limited to primary sources, which included camera traps, sightings, vocalizations, carcasses, feces, tracks and hair. For feces and hair, we only considered studies with data which were confirmed by DNA or hair analyses. Track records were limited to species that could be easily identified by this manner, like *Procyon cancrivorus*. Each record contained geographical coordinates, locality and the year that it was obtained. We always tried to use the precise coordinates for each record, but, when not possible, a centroid of forest remnant was used.

We converted a species presence into pixels of 1 km^2, in order to enable comparison with the other layers (Fig. 1). Then, we constructed a contingency table based on the presence of wild mammals under or outside cellphone coverage (Table A2), and we calculated the probability of a taxon being under a cellphone coverage area using the generalized linear model (GLM), considering the distribution of the binomial error (Nelder and Wedderburn, 1972). For the construction of this model and to estimate its coefficients, we used the function glm, as well as the function confint, in the package Stat within language R, to access its 95% confidence interval (R Development Core Team, 2016). We accounted for overdispersion when needed. The McFadden's pseudo R^2 was performed with function pR2 from the package pscl (Jackman

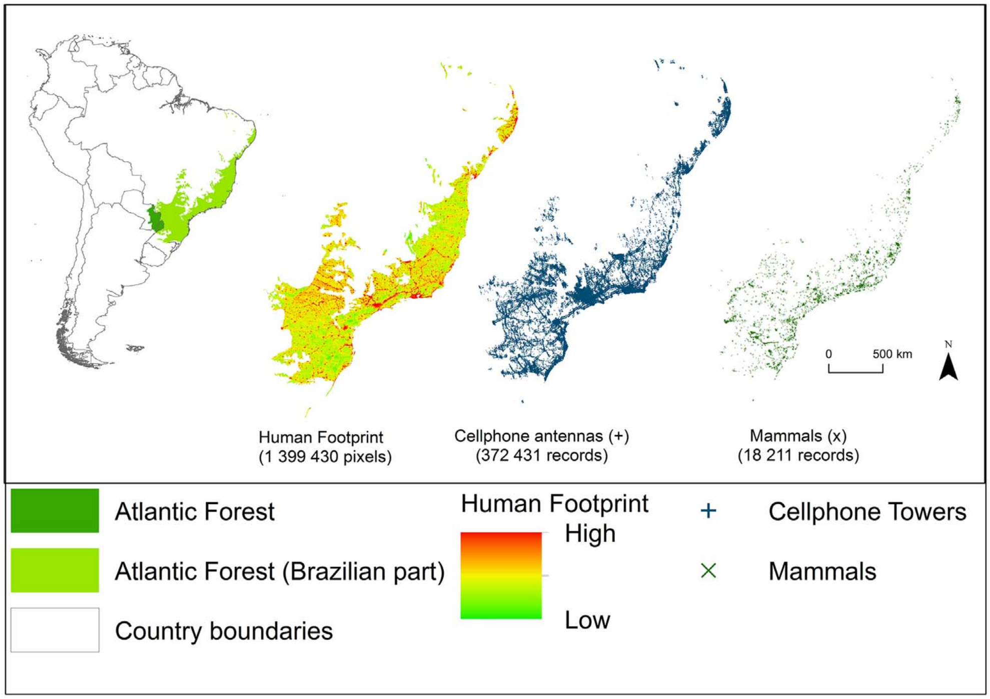

Fig. 1. Gradient of Human Footprint in 1 km^2 pixels, distribution of cellphone coverage and records of current mammalian presence within Brazilian part of the Atlantic Forest Hotspot.

et al., 2015).

3. Results

Among 219,078,498 pixels of HFP based on WCS and CIESIN (2005) data for the whole world, 4,559,709 (2.1%) were under cellphone coverage. There was a strong and positive relationship between the HFP index and cellphone coverage (z = 3435; df = 91; $p < 0.01$; $pR^2 = 0.96$) (Figs. 2A and 3). In Atlantic Forest biome, we estimated 76,266 pixels of HFP (5.4%) under cellphone coverage and an even stronger and significant relationship with HFP's score (z = 346; df = 59; $p < 0.01$; $pR^2 = 0.93$) (Fig. 2A). The mean of HFP score in this biome was of 33.4% ± 12.1%, *i.e.* two fold of the global score (15.4% ± 16.2%). Hence, the probability of presence of cellphone coverage increased with the HFP's score, especially above *ca.* 60%, independent on the scale, and both curves explained > 90% of the variation according to pseudo R^2.

Regarding Venter et al. (2016) data, there were 134,064,386 pixels with HFP in the world, where 3,643,750 pixels (2.7%) were under cellphone coverage. We again found a strong relationship between HFP and cellphone coverage (z = 3059; df = 49; $p < 0.01$; $pR^2 = 0.96$). When we focus only on the Brazilian Atlantic Forest, the relationship was also significant, but even stronger than the one found for WCS and CIESIN (2005) data (z = 363; df = 49; $p < 0.01$; $pR^2 = 0.98$) (Fig. 2B). In this biome, we observed a total of 1,119,184 pixels, with 71,037 pixels with at least one cellphone tower (6.3%). Furthermore, the map comparing roadless areas and cellphone coverage showed many patches where human influence could be identified only through the cellphone coverage methodology (Fig. 4).

Considering the HFP by WCS and CIESIN (2005), we were able to observe that globally 1067 pixels with cellphone coverage were considered as having zero human footprint. For Venter et al. (2016), this

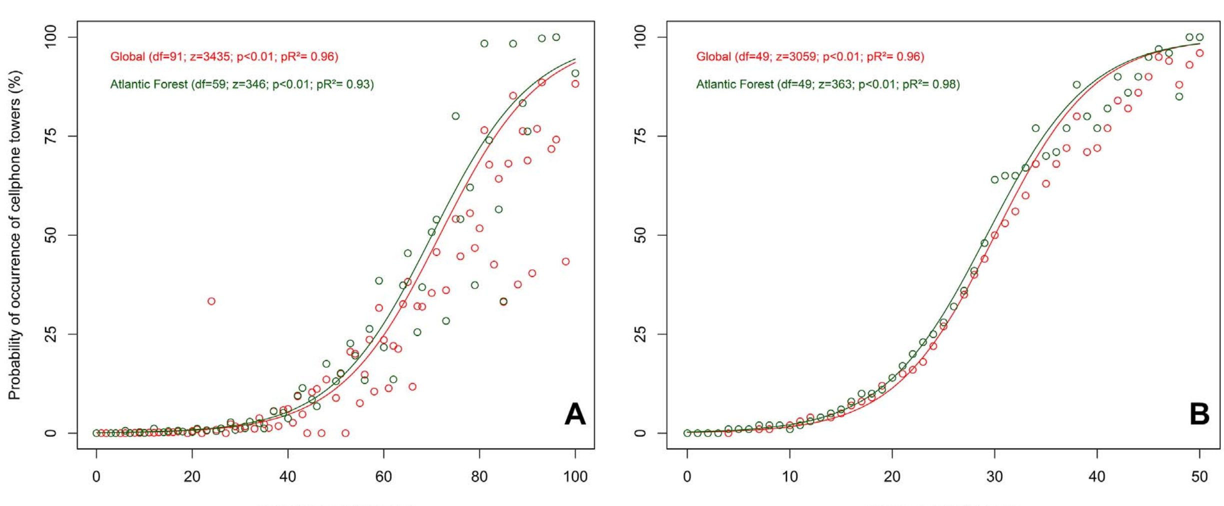

Fig. 2. The probability that a 1 km^2 pixel with a Human Footprint score has cellphone coverage within Atlantic Forest, Brazil. A. Using WCS and CIESIN (2005) data; B. Using Venter et al. (2016) data.

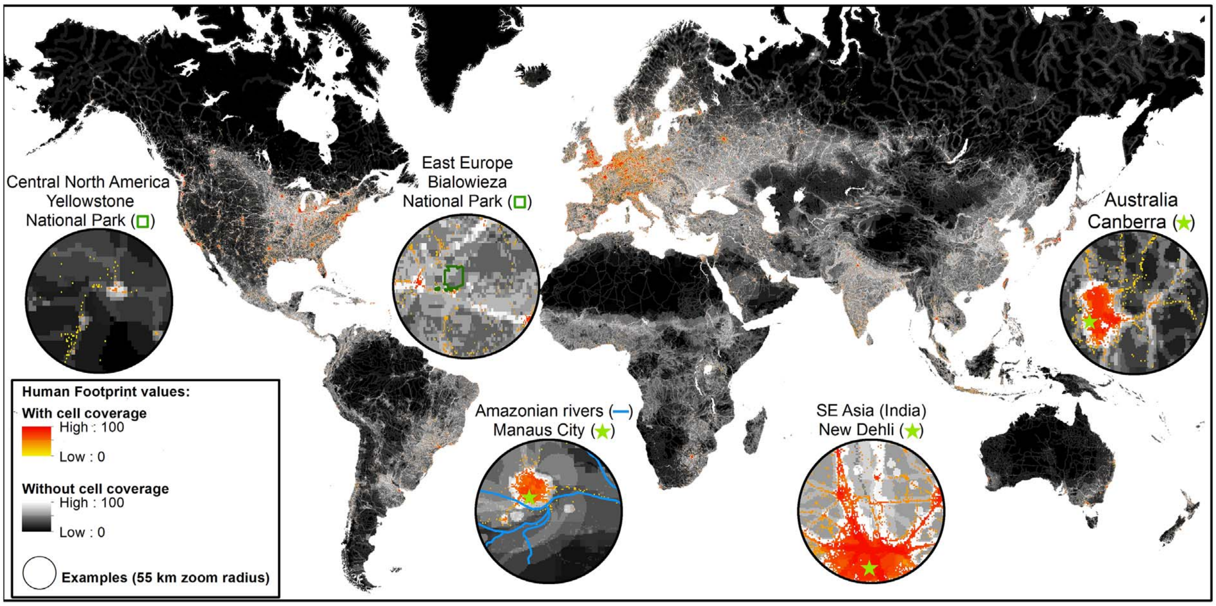

Fig. 3. The overlap between Human Footprint Index (*sensu* Sanderson et al., 2002) and cellphone coverage.

number is even higher, where 5025 pixels that were under cellphone coverage were considered as free from human influence. For the Brazilian Atlantic Forest, and considering WCS and CIESIN (2005), we found a minimal HFP of 6 in 2 pixels, whereas with Venter et al. (2016), we observed that 6 pixels showed a value of 1 for human footprint.

Once we demonstrated that cellphone coverage is a good proxy to evaluate human influence, we collected 18,211 points of presence for 45 species of wild mammals to assess how these species are responding to this influence (Table A2). Thus, we observed that the probability for a medium and large sized wild mammal to be under cellphone coverage was very low, considering all species: 18% [18–19%] ($z = -78.52$, $df = 0$, $p < 0.01$) (Fig. 5). Even more, the probability of a threatened species to be under cellphone coverage ($P = 14\%$ [13–15%], $z = -45.51$, $df = 0$, $p < 0.01$) was at least 4% lower than for a not threatened species ($P = 20\%$ [19–20%], $z = -63.72$, $df = 0$, $p < 0.01$). Most of the species (43 out of 45 species) showed clear negative relationship with cellphone coverage. The two exceptions were the Brown-throated Sloth (*Bradypus variegatus*), which showed a positive relationship with cellphone coverage ($P = 60\%$ [54–65%], $z = 3.40$, $df = 0$, $p < 0.01$) and the Oncilla (*Leopardus tigrinus*), which presented no significant results ($P = 35\%$ [20–53%], $z = -1.53$, $df = 0$, $p = 0.11$) (Fig. 5 and Table A2).

4. Discussion

4.1. Cellphone coverage capturing human influence

This is the first study demonstrating that cellphone coverage can be used as a simpler, modern and unprecedented tool to assess human influence. It is noteworthy that all Human Footprint Indexes, published by Sanderson et al. (2002), WCS and CIESIN (2005) and by Venter et al. (2016), did not included cellphone coverage in their constructions, although in the first case, the technology was still incipient in the world. Still, it should be kept in mind that the indexes of human influence

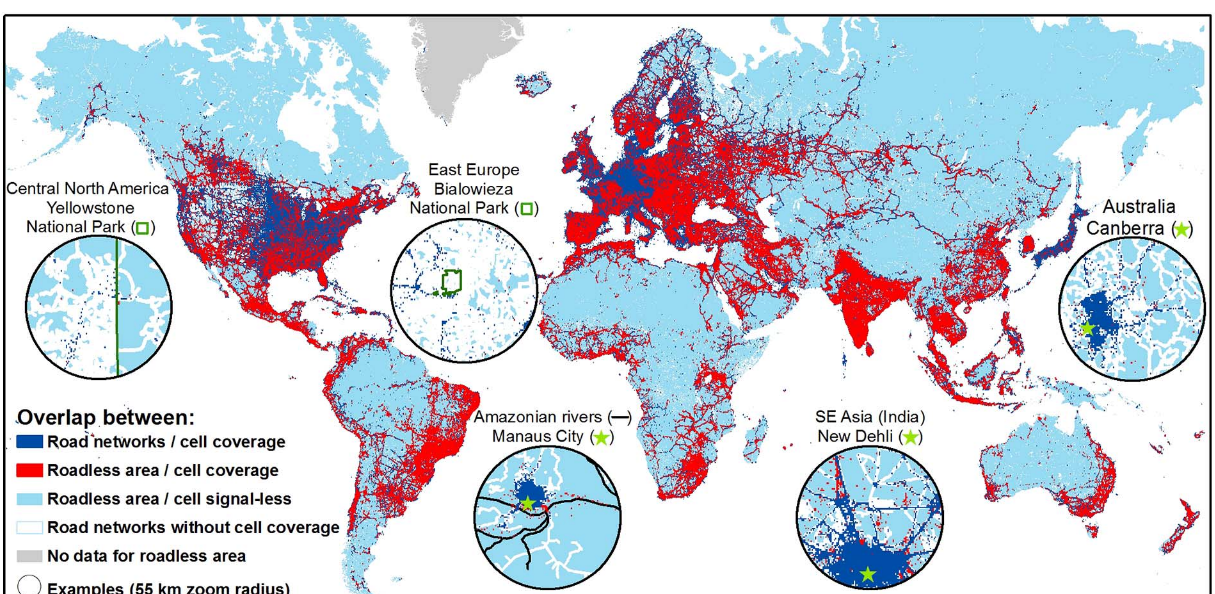

Fig. 4. The overlap between road networks, roadless areas (*sensu* Ibisch et al., 2016) and cellphone coverage.

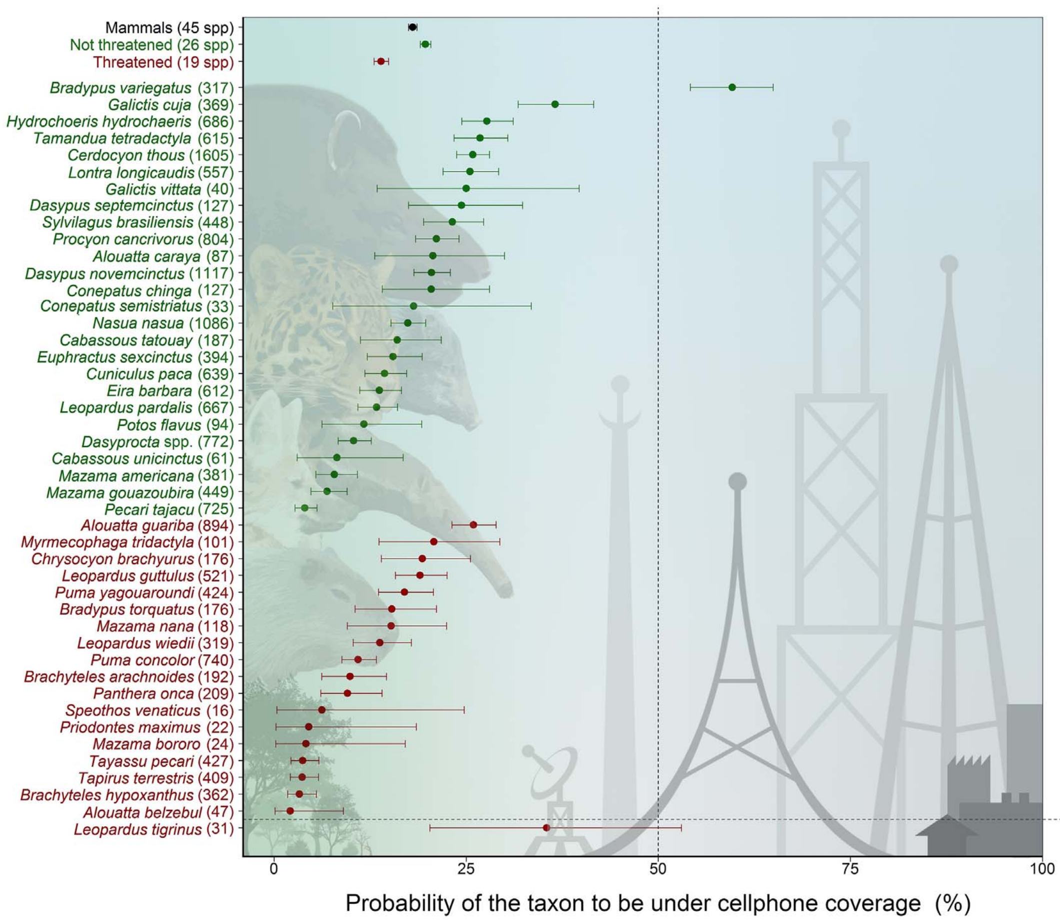

Fig. 5. The probability of a medium and large sized wild mammal species to be found under cellphone coverage in the Brazilian Atlantic Forest Hotspot. Conservation status of species distinguished by color: green (not threatened) and red (threatened). Dashed vertical line: probability of a taxon to be under (right side) or out (left side) cellphone coverage. Under dashed horizontal line: species without cellphone coverage effect. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

represent a certain period of time in the past, therefore presenting some delay in relation to the human pressures in the environment (Venter et al., 2016). Hence, besides from being promptly updated, since new cellphone towers are registered on a daily basis, this new methodology also carries some easiness in its use. Moreover, using cellphone coverage brings a refinement that is absent from other tools, once they are recorded in places that are sometimes overlooked or difficult to access. For example, many accessory roads that lead to cellphone towers or power transmission are not represented in information maps (shapefiles).

Moreover, once cellphone coverage was detected in areas with very low values of Human Footprint, including even sites where its value was equal to zero, this new methodology shows itself as sensible to human influence. Acknowledging that cellphone coverage is quicker to respond to human influence, the fact that we did not observe pixels with zero HFP under cellphone coverage in the Atlantic Forest can be interpreted as this biome being highly anthropized. Biomes like the Brazilian Atlantic Forest, with an ongoing, but older process of impoverishment, present only few areas free from a human footprint. On the other hand, areas more in the beginning of the process of deforestation may present many sites with cellphone towers that were not already registered as human influenced by HFP. Therefore, in a world experiencing an increasing human pressure, many times beyond what it can handle (Dirzo et al., 2014; Steffen et al., 2015), a more instantaneous methodology to assess its influence is much needed.

Regarding the roadless areas, another human influence proxy, cellphone coverage shows itself as more sensible, pointing out unexpected areas where humans are present, like the Amazon region, which presents large blocks of roadless areas (Ibisch et al., 2016). There, even though the density of roads is low, anthropogenic activities are still felt, because rivers are used as alternative routes allowing humans to spread through (Fig. 4). In this way our methodology can be used as a complement, or buffer, to the indicator proposed by Ibisch et al. (2016), well adjusting to areas where roads are not the main way for human movement. Once that minimal population density required for the installation of cellphone towers is met, part of these roadless areas, previously considered human influence free, is in fact not.

The correspondence between cellphone coverage is directly linked to the density of cellphone customers, that is, human influence intensity. An explosively growing market for the installation of new towers in developing countries reflects a human population expansion in these places. Once these same countries concentrate and preserve the largest quantity of species in the world (Hawkins, 2001; Brown, 2014), the use of cellphone coverage could aid in pointing areas where human influence are enhancing, but are still not accounted for by other methodologies. Besides, as it is expected an improvement in the quality of service given to customers, *via* an enhancement in cellphone coverage with the installation of new towers, we could only foresee an uplift in our methodology, getting progressively more precise and refined. On the other hand, if we apply an inverse logic, we may be able to distinguish areas free from cellphone coverage and, therefore, from human influence. In this way, cellphone coverageless areas, together with roadless areas, may contribute to point out which remnants could be invested to more efficient directions in conservation managements.

Cellphone coverage gains more power when we consider that satellite images, an often used tool to monitor deforestation, many times show a large and continuous forest mass as free from humans. However, cellphone coverage may indicate that this is not necessarily true in forests inhabited or even influenced by humans, because its effects on biodiversity cannot be easily detected under the canopy (Dirzo and Miranda, 1990; Redford, 1992). Therefore, the cellphone coverage methodology may come as an aid, distinguishing two equally sized patches that would be mistakenly considered as having the same value when we look at them only through satellite images.

However, some cautions should be considered when using cellphone coverage to assess human influence. Firstly, since we considered that each antenna has a coverage of 1 km^2, a mean value of coverage suggested by GSM Association, the use of pixels bigger than 1 km^2 also causes homogenization. In this case, single antennas in bigger pixels would have their coverage overestimated. Secondly, the pixels size should be kept small ($\leq 1\ km^2$), so that mosaics containing a mixture of patches with low and high human footprint could be discriminated. This avoids the homogenization of areas that share heavily altered sites with more pristine areas which may still maintain a preserved fauna. This is the case for protected areas immersed in a matrix of high intensity of human footprint, *e.g.* Tijuca National Park, which is surrounded by the city of Rio de Janeiro. A grid with large pixels, for example, would mask the differences that we have found in our study case, since the cellphone coverage and the presence of fauna would be registered as sympatric when in reality they are not.

We should also remark that cellphone coverage was based on a presence-absence data. However, it is possible to use the density of antennas inside each pixel as a measure of intensity of human influence. Therefore, some gradation in human influence can be obtained from cellphone towers data. Here, we opted to something quicker and simpler, but this method does not exclude the possibility of some refinement.

4.2. A study case in the Brazilian Atlantic Forest

This work is the first to demonstrate the negative correspondence between cellphone coverage and the presence of wild mammalian species. The cellphone coverage *per se* is not a cause for the negative relationship but stands as a simple surrogate of the multivariate and complex human footprint. In this matter, we can observe that most of our studied species presented a probability lower than 30% to be in areas with cellphone coverage. Larger sized mammals showed an even clearer pattern of avoidance to human influenced areas. The genus *Brachyteles*, and the species *T. pecari*, *T. terrestris*, *P. onca* and *P. concolor* for example, presented a smaller probability to be under cellphone coverage, lower than 11%.

However, two species showed a different pattern, *Bradypus variegatus* and *Leopardus tigrinus*. A first look would give the idea that *B. variegatus* preferred environments with cellphone coverage, that is, with greater human activity. Although we are aware that some species can benefit from environmental changes, mainly due to the absence of predators (*e.g.* Fonseca and Robinson, 1990; Graipel and dos Santos Filho, 2006), we do not believe that it was the case for this sloth. This apparent preference may result from the type of records obtained, since most of its data consisted of roadkill and sightings by citizens in roads or habitat remnants near urban centers, which have cellphone coverage. In addition, *B. variegatus* is an arboreal species, and its cryptic feature makes recording even more difficult in a natural environment. On the other hand, *B. torquatus* showed a different pattern from its congeneric species. This sloth is little detected near anthropogenically altered sites, and once it is considered a threatened species, it has been subject of several groups of studies that specifically and actively search for it in more preserved forests, with a higher and more connected canopy (Cassano et al., 2011; Santos et al., 2016). This would explain the distinct responses of these two species when regarding cellphone coverage.

Moreover, *Leopardus tigrinus* seemed to have no significant preference for any type of habitat, with or without cellphone coverage. Once it was recognized as three distinct species, *L. emiliae*, *L. tigrinus* and *L. guttulus* (Nascimento and Feijó, 2017), they probably present very similar ecologies. Then, this result can be in tune with what was pointed by Oliveira-Santos et al. (2012) that observed a thriving *L. guttulus* in harsh and impoverished environments in southern Brazil, where other cats no longer exist.

Regarding our data of wild mammals' records, we should remark that they span from 1839 until 2016, but > 90% of the values are concentrated after the year of 1990. We are aware that many ancient records may be present in what nowadays are cities, surely under cellphone coverage, what would weaken our results. Nonetheless, despite this fact, we still found a very strong and negative relationship between wild mammal records and cellphone coverage, what makes us certain that the removal of these ancient records would only make our results even stronger, reinforcing the pattern found.

Other matter that could be pointed as a limitation is that our data has a bias, since records are limited to areas where human can access. Logically, each point of registration of a species implies that a human was at that point obtaining the information and that he accessed this particular site in some way. For this reason, the most pristine areas of the human footprint gradient (HFP < 10) have very low density of mammalian records. These places also lack cellphone coverage, not due to a faulty record, but because cellphone towers are in fact not installed. Following Ceballos and Ehrlich (2002), it is reasonable to assume that it is precisely in these non-sampled sites where nature flourish and also where we could find the greatest species richness, since the negative relationship between richness and footprint intensity is observed in the rest of the gradient. Therefore, we can affirm that the inclusion of these mammalian data from more preserved areas would only corroborate and even reinforce this negative pattern found. Hence, we consider that our results are very cautious; the reality must be much more dramatic than we have been able to quantify.

Besides from what cellphone coverage represents itself, that is, human influence, we must also remark on the few changes in environment that comes with the presence of towers, once access routes, that allow their installation and maintenance, are created. Cellphone towers allow access, at least in part, to regions which could otherwise be considered with no human influence (Ibisch et al., 2016). These routes may lead to negative impacts on wildlife through edge effect and deforestation (Fuentes-Montemayor et al., 2009; Maynard et al., 2016)

The Atlantic Forest has only 9.4% of its surface sheltered by full protection conservation units. Within this area, 94.5% has no cellphone coverage yet. Thus, given the negative correspondence between cellphone coverage and presence of mammals, and its positive relationship with the human footprint, the cellphone coverage methodology can be used to monitor the increase of human influence in preserved areas. Due to the easy use of this methodology, and once it is daily updated, cellphone coverage could serve as an early warning to dangerous changes in the few protected remnants of the Brazilian Atlantic Forest. This is because an increase in cellphone coverage may indicate a human demographic growth, with a consequential environment disturbance and possibly the extirpation of species. Therefore, the use of this new methodology brings some aid, even more in a hotspot like the Atlantic Forest, where the defaunation has been shown relentless, with the extirpation of some species, as *P. onca*, *T. pecari*, and *T. terrestris* (Canale et al., 2012; Jorge et al., 2013; Mendes Pontes et al., 2016), and where any area that can be maintained is essential for the conservation effort.

At last, once we demonstrated that the relationship between cellphone coverage and human footprint is highly significant (Fig. 2), and that the use of this new methodology may ease future studies, the replication of a similar study case in other parts of the world is very possible. For that, it should be noted the need for detailed presence records for the chosen species, and that the cautions mentioned towards the handling of the cellphone coverage data are taken (see the topic Cellphone coverage capturing human influence).

5. Conclusions

We do not intend to replace the Human Footprint Index with cellphone coverage. Instead, we want to provide a new indicator extending the significance of human presence on a local scale. This new methodology is a more sensible indicator to human influence, more easily to be applied, and daily updated with data of new cellphone towers being installed.

Our results show that the vast majority of medium and large sized mammalian wildlife in the Brazilian Atlantic Forest does not occur in areas influenced by humans. Besides, when we separated the species in threatened and non-threatened, according to the Brazilian Red List criteria (MMA, 2014), it was possible to observe a significant difference. Nevertheless, threatened or not at a national level, it is alarming to see that most species of medium and large mammals, except for *B. variegatus* and *L. tigrinus*, are negatively sensible to human influence (Fig. 5), what would put them in an even bigger danger to disappear from the Atlantic Forest due to the advance of human footprint (Venter et al., 2016).

As it was pointed out by Venter et al. (2016), there was an enhancement in human footprint in all Brazilian Atlantic Forest between the years of 1993 and 2009. Therefore, as it is known that a bigger human footprint index can lead to extirpations, cellphone coverage may work as an early warning once it is daily updated. In this sense, we should also remark that the last Human Footprint Index was published almost 10 years ago. Then, the cellphone coverage methodology could be used by governments as a tool to indicate areas of higher concern, in which more should be invested on, especially when dealing with conservation units.

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Appendix A. Supplementary data

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