Habitat loss estimation to assess terrestrial mammal species extinction risk: an open data framework

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Abstract

Terrestrial mammals face the most severe crisis of habitat loss worldwide, making this crucial information to assess the species' conservation status through the IUCN Red List system. To support the national extinction risk assessment in Brazil (2016-2022), we developed a script that uses the MapBiomas 6.0 data source of land cover and land use (annual maps at 30m scale) within the Google Earth Engine (GEE) platform to calculate habitat loss for 190 terrestrial mammal species. We defined the suitable habitat from the MapBiomas land cover classification for each species according to the species distribution and ecology. For the time-window, we considered the period of three generations length. We used the script to estimate changes in the available habitat along the analyzed period within the species' known range. The results indicated that habitat loss occurred within the range distributions of 94.3% of the analyzed taxa, with the order Carnivore suffering the highest habitat loss, followed by the Cingulate order. The analyses may be decisive for applying criteria, defining categories in the assessment for at least 17 species (9%), enriching the discussions, and raising new questions for several others. We considered the outcome of estimating habitat losses for the various taxa when applying the criterion A – referring to population reduction, thus supporting more accurate inferences about past population declines.

Keywords: Mammalia; threatened species; deforestation; habitat change; IUCN Red List

1 Introduction

Habitat loss and fragmentation significantly impact biodiversity, leading to critical population declines and affecting long-term biodiversity conservation (Fahrig, 2003; Ferraz et al., 2021; Santos et al., 2019a). Despite natural habitats occupying only 16% of the world's land surface nowadays (IPCC, 2021), such areas are strongly affected by anthropogenic activities (Haddad et al., 2015; Leblois et al., 2017). Decreasing the amount of available habitat might directly affect critical biological processes, such as resource availability (Ryser et al., 2019), dispersal (Cote et al., 2017), pollination (Pavageau et al., 2017), and gene flow (Dixo et al., 2009; Moraes et al., 2018), thus, decisively contributing with the population reduction (Harfoot et al., 2021; Heinrichs et al., 2016; McCormack et al., 2019).

Worldwide, more than 30,000 species are at risk of extinction - ultimately due to habitat reduction, disturbance, and fragmentation – wherein 26% correspond to mammal species (IUCN, 2020). Notably, the Mammalia order is essential since it plays a critical role in ecosystem functioning (Jorge et al., 2013; Magioli et al., 2021; Rodrigues et al., 2019). Albeit, those factors highly threaten the group (Bogoni et al., 2020; Canale et al., 2012). Consequently, mammals have suffered from anthropogenic impacts and have been victims of several human-wildlife conflicts (Adhikari et al., 2022; Desbiez et al., 2020; Vanak and Gompper, 2010), with continuous population reduction over the last decades (IUCN, 2020).

Reducing the species extinction risk – particularly for highly threatened taxa – is a global priority, and figures among various international agreements for biodiversity conservation, such as in the Convention on Biological Diversity Aichi Target 12 (https://www.cbd.int/sp/targets/) and the United Nations Sustainable Development Goal 15 (https://sdgs.un.org/goals). In order to assess the extinction risk for known species, the International Union for Conservation of Nature (IUCN) conducts global conservation status assessments, using a well-established methodology along with rigorous theoretical and analytical data (IUCN, 2019). Based on specific biological parameters and definitions, such as population sizes and trends, geographic range and occupancy, population reduction, and generation time (IUCN, 2019, 2012), the IUCN's assessment process has established the worldwide used extinction risk categories (e.g., Critically Endangered, Least Concern and Data Deficient), criteria (Criteria A to E) and assessment methodology.

Although there is a lack of primary biological data for many taxa (IUCN, 2019), the IUCN's methodology comprehends a variety of data types from many sources and quality (with the terms Observed, Estimated, Projected, Suspected, and Inferred referring to the different sources and data quality). For example, the IUCN's Criterion A – widely used to assess mammal species risk of extinction – highlights taxa that have undergone intense population reductions either in the recent past or projected for the near future. However, only a handful of taxa have direct observation of population reduction. Thus, other types of data – such as an index of abundance, a decline in habitat quality, levels of exploitation, or effects of pathogens – may be used as a basis for estimation, inference, or suspicion of population reduction. Habitat loss estimates within a taxon's range, area of occupancy, or extent of occurrence may be used as an essential tool for the extinction risk assessment, as a proxy of population reduction, especially for those species strictly related to or dependent on its proper natural habitat (IUCN, 2019).

Habitat loss significantly impacts Brazilian territory, which lost 82 Mha between 1985 – 2020 (MapBiomas, 2021), directly affecting several taxa. In Brazil, there are around 770 mammalian species (Abreu et al., 2020), leading the country to the second-largest mammal diversity in the world and the largest for some of its orders, such as Primates (Chiarello et al., 2018) and Xenarthra (Santos et al., 2019b). Although having this enormous mammal biodiversity, exceptional levels of deforestation affect mammal species in all Brazilian biomes (Bogoni et al., 2020; Magioli et al., 2021), including Amazon - habitat with the highest species richness, Atlantic Forest - with increased rates of endemism (Chiarello et al., 2018), and Pantanal - which lost about 17 million vertebrates over the past two years due to wildfires (Tomas et al., 2021).

Throughout the years, either the high number of threatened species or the immense number of unassessed taxa indicates the necessity for more efficient risk of extinction assessments, including the generation of new data and metanalyses to support IUCN's categories and criteria application. Therefore, using open data, such as land use and land cover satellite imagery, may be a promising tool to support extinction risk assessments and guide decision-making (Ferraz et al., 2021). Besides, performing metanalyses with open data would ultimately contribute to a higher reproducibility, replicability and data cycle – the basis of open science philosophy (Gallagher et al., 2020) – within the assessment process. South America currently counts with the MapBiomas project, a collaborative network formed by NGOs, universities, and technology startups (MapBiomas, 2021). This project has produced land cover and land use maps since 1985 – besides other products such as fire and deforestation reports. The MapBiomas is updated yearly and includes all Brazilian and some South American Biomes (Amazon, Chaco, Pampa, and Atlantic Forest) and recently Indonesia. Along with the Google Earth Engine technology – a cloud-based platform with a vast satellite image collection catalog (Gorelick et al., 2017), MapBiomas may be used to produce land cover change estimates in a faster and more efficient manner without requiring local supercomputers.

Using the IUCN Red List methodology (ICMBio, 2013), the Chico Mendes Institute for the Biodiversity Conservation (*Instituto Chico Mendes de Conservação da Biodiversidade* - ICMBio), linked to the Brazilian Ministry of Environment, coordinates and conducts the official national extinction risk assessments of the fauna. ICMBio has already conducted a participatory assessment of more than 12,000 taxa in the last decade, including all 8,818 vertebrates known to occur in the country by 2018 (ICMBio, 2018). The National Centers for Research and Conservation Brazilian Primates and Xenarthras (CPB/ICMBio) and Carnivorous Mammals (CENAP/ICMBio) coordinate the Brazilian extinction risk assessment for more than 700 taxa of terrestrial mammals occurring in Brazil (ICMBio, 2021).

This study established a systematic approach to estimate habitat loss for Brazilian terrestrial mammal species using time series of land use classification maps to generate necessary and accessible information to subsidize the application of IUCN's categories and criteria for Brazilian extinction risk assessments. Therefore, we used a series of land-cover maps from the MapBiome project to generate a cloud-based, open data framework - using the Google Earth Engine platform (GEE) - that allows habitat loss estimation through different time scales. We demonstrate the applicability and use of the habitat loss calculation platform with 190 Brazilian mammal taxa, including the Orders Carnivora, Cetartiodacyla, Cingulata, Perissodactyla, Pilosa, and Primates. Ultimately, this approach provides a habitat loss calculation platform that might be easily replicated for other taxa to subsidize assessments, decision-making for conservation, and increased knowledge on how intensely and where habitat loss may be affecting taxa worldwide.

2 Methods

2.1 Studied System

The 8.5 million km^2 Brazilian continental area harbors around 188 species of terrestrial, medium to large size mammals (Abreu et al., 2021), among those about 30% considered threatened with extinction (MMA, 2014). In the present study, we used the Conservation Categories from 2010 – 2014 cycle. We included a total of 190 mammal taxa (mainly at the species level but also including a handful at the subspecies level) representing six orders: Carnivora (28 species), Cetartiodactyla (11 species; only terrestrial taxa), Cingulata (11 species), Perissodactyla (1 species), Pilosa (12 species) and Primates (127 taxa). We included five small-sized mammals (*Cyclopes didactylus*, *C. ida*, *C. rufus*, *C. thomasi*, and *C. xinguensis*) to cover all Xenarthran species occurring in Brazil. Additionally, we calculated the habitat loss separately for each distribution block for species with disjoint distributions (*Bradypus variegatus* and *C. didactylus*).

2.2 Extinction Risk Assessment of Brazilian Species

The assessment of the extinction risk of the Brazilian fauna - conducted by the ICMBio - involves the scientific community (experts) and stakeholders worldwide. Through this process, each taxon has a specific form containing information about its taxonomy, distribution, population, conservation and threats, including essential information used for the taxon's extinction risk assessment. All data information is organized in the databank System for the Conservation Status Assessment of the Brazilian Biodiversity - SALVE (*Sistema de Avaliação do Estado de Conservação da Biodiversidade*) (SALVE System, 2020). This Brazilian assessment process uses the IUCN Red List methodology for regional assessment, including its criteria, categories, and quantitative and qualitative analyses (ICMBio, 2013; IUCN, 2012). Therefore, ICMBio uses eleven categories (two more than the IUCN Global Assessment) for classifying species risk of extinction (IUCN, 2012; ICMBio, 2013). Any biological knowledge of importance for the assessment is analyzed within this process with rigorous quantitative criteria to meet one of these categories.

The population reduction, related to the application of Criterion A, is one of the parameters used to identify whether a taxon had/will suffer some level of population (number of mature individuals) decline in either ten years or three generations - whatsoever is longer (IUCN, 2019). However, most species lack direct observation or long-term populational studies allowing confident estimation of population reduction. Hence, other parameters, such as the decline of Area of Occupancy (AOO), Extent of Occurrence (EOO), or habitat quality (IUCN, 2019), might be used to infer or suspect a population reduction.

As the population reduction must be estimated within a time window of three-generation length (3GL) or ten years (whichever is longer) (IUCN, 2019), this parameter must be calculated according to IUCN's definitions. For IUCN, Generation Length (GL) is defined as "*the average age of parents of the current cohort (i.e., newborn individuals in the population*)" (IUCN, 2019), reflecting the turnover rate of mature individuals of a population. The GL might be calculated in several ways. For this study, we adopted the following equation:

$$GL=AFR+(z*R_{span})$$

Where: GL = Generation Length, AFR = Age of First Reproduction, R_{span} = species reproductive life span, defined as the difference between the age at last reproduction and the age at first reproduction, and z is a constant, which "*depends on survivorship and relative fecundity of young vs. old individuals in the population*" (IUCN 2019). In this study, we adopted z = 0.5 (Pacifici et al., 2013; IUCN, 2019). Since some species have no essential information to calculate the GL, we adopted the GL estimated by Pacifici et al. (2013), also recommended by the IUCN red list guidelines (2019). For primates, we adopted the GL estimated by the experts at the IUCN's Neotropical Primates Species Assessment Workshop in 2007.

2.3 Habitat loss estimative

We used each taxon's geographical distribution to estimate the habitat loss. This area consists of a polygon delimited by the occurrence records (obtained through literature or personal communication with the assessors), adjusted with the known biogeographical limits for the distribution of each taxon (e.g., rivers or relief), and according to the available literature or expert knowledge, when possible.

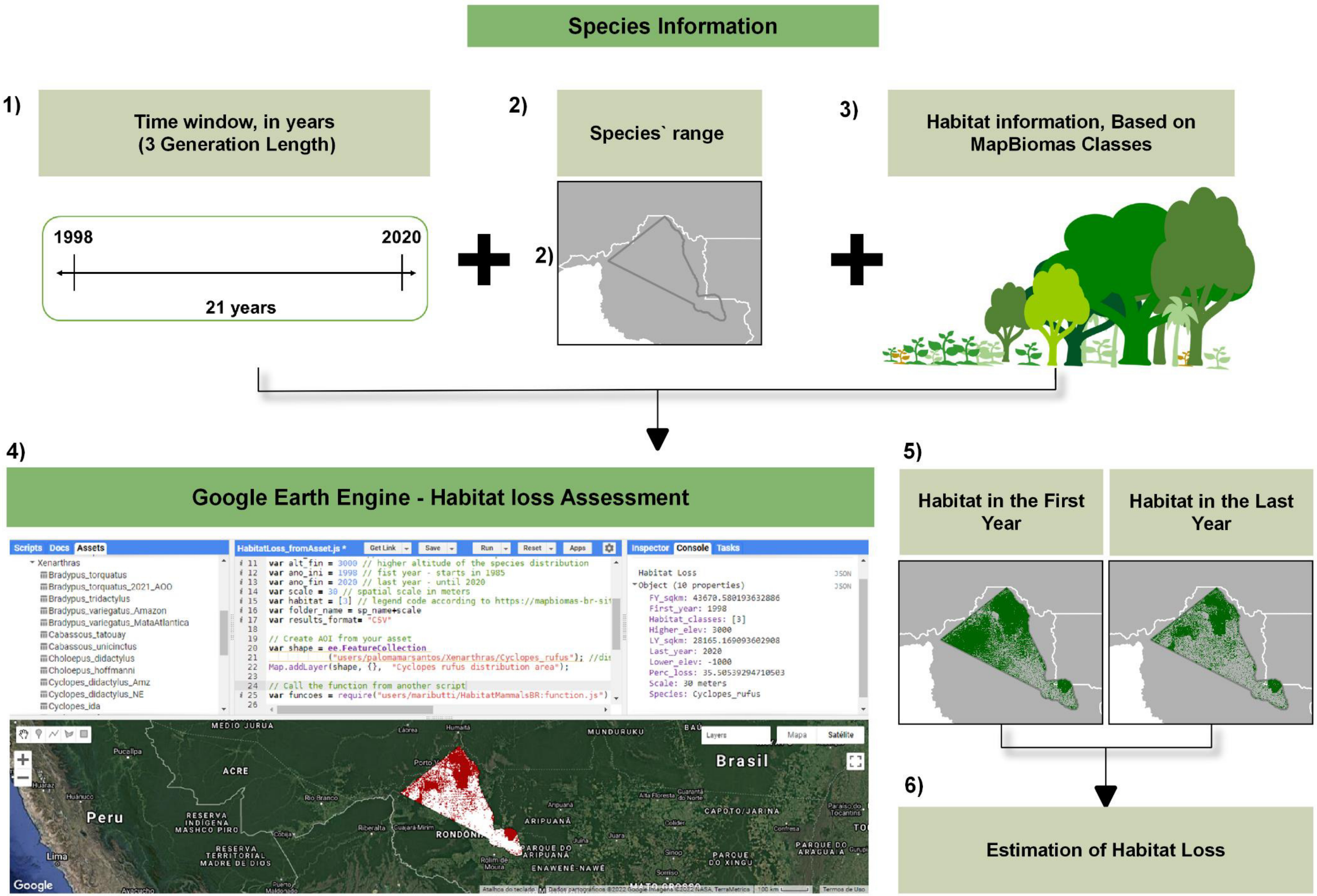
We used the MapBiomas Project - Collection 6 (MapBiomas, 2021), which has produced land use and land cover (LULC) data from 1985 to 2020, to estimate the habitat loss. We first identified the LULC classes that constitute each species' suitable habitat; then, we remapped the pixels within the distribution ranges to either 0 or 1 values, representing the non-habitat (0) or habitat (1) classes. Finally, after this pixel reclassification, we estimated habitat loss using the following equation:

$$HL= [1-(HLY/HFY)] *100$$

where HL = Percentage of Habitat Loss, HFY = Total habitat area of the first year of the time window (which is the sum of all pixels equal 1 in the first years' map), HLY = Total habitat area of the last year of the time window (sum of all pixels equal 1 in the last years' map). We established 1985 as the first year of the time window for those taxa with 3GL greater than 35 years because that is the older available spatial data provided by the MapBiomas project (MapBiomas, 2020). Therefore, habitat loss might be underestimated for these taxa.

We developed the script for habitat loss calculation using Google Earth Engine (GEE), and the code is available at:

https://code.earthengine.google.com/?accept_repo=users/maributti/HabitatMammalsBR. This script allows the user to access the MapBiomas database online. Then, for calculating habitat loss, the user may select both the initial (ano_ini) and final (ano_fin) years – corresponding to the time window (3GL) for the target species, the scale (minimum = 30 m, which is the default resolution of MapBiomas), and the corresponding habitat(s) that are suitable for the target taxon (according to the MapBiomas Classes ID code). Additionally, it is possible to select upper and lower elevation limits to apply a mask to the habitat layer based on that range. Therefore, all habitat classes outside the selected range are reclassified to non-habitat (0). We used the NASA-SRTM (Shuttle Radar Topographic Mission) dataset (Jarvis et al., 2008) to implement this layer mask. In this study, we set up the limits out of Brazil's altitudinal range ([-1000, 4000]) as no species has elevation boundaries (Figure 1).



Species Information
1)
Time window, in years
(3 Generation Length)
1998
2020
21 years
2)
Species` range
3)
Habitat information, Based on
MapBiomas Classes
4)
Google Earth Engine - Habitat loss Assessment
5)
Habitat in the First Year
Habitat in the Last Year
6)
Estimation of Habitat Loss

Figure 1: Workflow explaining the inputs and outputs referent to the habitat loss estimation using our scrip through Google Earth Engine (GEE): 1) Calculate the GL for the target taxon and the time window (= 3GL). For this example, we used the GL of *Cyclopes rufus* = 7 years, then 3GL = 21 years; 2) Map the taxon' range and upload the file to the GEE; 3) Identify the habitat classes suitable for the target taxon, according to the MapBiomas Classes; 4) Include all these input information on the script at GEE and run the model; 5) Maps of both first and last years of the time window (3GL) are generated to estimate habitat loss; 6) Habitat loss estimation output: the model run generates a CSV file with all the output information.

We uploaded the taxon range file in vector format to perform the analyses on the GEE platform. The vector file must necessarily contain: .shp, .shx, .dbf and .prj extensions. Our habitat loss calculation script also makes it possible to draw a random polygon directly in the map displayed at the GEE to calculate the habitat loss in a specific area. Each taxon was analyzed separately, resulting in ten output parameter information (Table S1). The script model run generates results in three file data, available for download: CSV file, with all the requested information, and two raster files in .tiff, with the spatialized habitat of both the first and last years, corresponding to the taxon time window. The default projection is WGS84-CGS, but it is possible to choose any other Coordinate Reference System (CRS) when saving the file. It is also possible to save the files on Google Drive, in the cloud storage, or the GEE Asset, dispensing with the obligation to save in the user's local computer.

2.4 Data Analyses

We performed descriptive statistics with the resulting habitat loss data. These analyses included mean, median, quartiles, standard deviation, and the maximum and minimum value for habitat loss, according to Conservation Category (CR – Critically Endangered, EN - Endangered, VU - Vulnerable, NT – Near Threatened, LC – Least Concern, DD – Data Deficient, NA – Non-Applicable, and NE – Not evaluated); Conservation Status (Threatened – CR, EN, and VU; Non-threatened – NT and LC; None of the conservation status – DD, NA, and NE) and Taxa's Order (Carnivore, Cetartiodactyla/Perissodactyla, Cingulata, Pilosa, and Primates). As the Perissodactyla order harbors only one species (*Tapirus terrestris*), we opted to include this taxon into the same group as the Cetartiodactyla order for these statistical analyses performed. To simplify the discussion, we arbitrarily categorize the habitat loss into three categories: High habitat loss - ≥ 30% (considering the minimum threshold of population reduction to classify the species in some of the threatened categories based on Criterion A); Moderate habitat loss – ≥ 20% and < 30% (considering the proximity to the previous threshold, which could lead the species to be categorized as Near Threatened); and Low habitat loss - < 20% (which could lead to a species categorization as Least Concern by Criterion A).

3 Results

We successfully developed an open script that allows estimating habitat loss for each species of interest using a series of LULC maps from the MapBiomas project through the GEE platform. We tested the application of the habitat loss calculation script on 190 mammal taxa, covering different orders, habitat types, and conservation status. The mean habitat loss was 6.46 (±8.23), but with a high data variation, considering the maximum and minimum values varied from 34% to -19.92% (Table 1). Observing the three target classes (Conservation Status, Conservation Category, and Order), the mean habitat loss follows this general trend of a high degree of habitat loss variation (Table 1).

Table 1: Basic statistics of the results from the habitat loss calculation script run on the 190 mammal taxa included in this study. SD = Standard Deviation; Max = Maximum values of habitat loss for that class; Min = Minimum values of habitat loss for that class; Var = Variation between the minimum and maximum values.

		Mean	SD	Max	Min	Var
	Total	6.48	8.22	34.07	-19.92	53.99
Conservation Status/Category	**Threatened**	7.79	9.62	32.84	-8.19	41.03
	CR	11.10	14.75	32.84	-1.12	33.96
	EN	2.27	7.35	13.19	-8.19	21.38
	VU	9.54	8.79	31.88	-1.17	33.05
	Non-Threatened	5.22	7.06	31.77	-19.92	53.99
	NT	13.22	11.17	31.77	-4.69	36.46
	LC	4.24	5.75	24.44	-19.92	44.36
	None	8.06	8.53	34.07	0.40	31.37
	DD	5.06	5.94	25.10	0.40	25.10
	NA/NE	11.43	9.85	34.07	0.45	34.07

Order	**Carnivora**	8.81	6.53	26.17	0.95	25.21
	Cetartiodacyla/Perissiodactyla	7.87	7.39	23.90	0.40	23.50
	Cingulata	7.35	8.84	31.77	0.61	31.16
	Pilosa	7.43	12.28	34.07	-19.92	53.99
	Primates	5.66	8.03	32.84	-8.19	41.03

When comparing the Conservation Status, the three categories presented a similar habitat loss (Figure 2), with species from status "None" suffering the highest (Table 1). The NT category presented the highest habitat loss for the Conservation Category, followed by the "NA/NE" (Figure 2; Table 1). Finally, all five analyzed orders had a similar habitat loss, with the order Carnivore suffering the highest values, followed by the Cingulate order (Figure 2; Table 1).

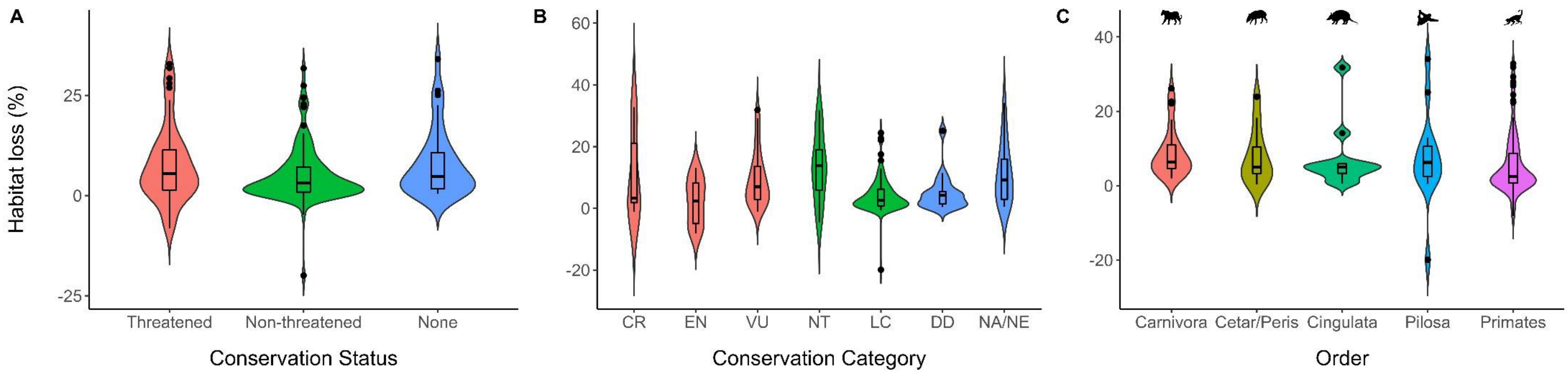


Figure 2: Boxplots of the resulting habitat loss data for A) Conservation Status categories; B) Conservation Category; and C) Order. The box plot presents the minimum, maximum, the first and the third quartile, and the median. Data beyond the end represent the database outliers. Cetar/Peris indicates the Cetartiodactyla and Perissodactyla orders, respectively.

Most taxa included in this study (71%) suffered between 0 – 10% of habitat loss within their distribution, followed by 14% of the taxa that suffered between 10 – 20% of habitat loss. Only four taxa (2% of all included in this study) underwent a habitat loss higher than 30% – three of them already considered threatened with extinction, and one previously categorized as Near Threatened (Table S2). About 6.8% of the analyzed taxa's range (13 species) suffered a habitat loss between 20 and 30% (Figure 3), including five species (38.46%) already threatened with extinction (Table S2). Less frequently, some taxa (6% - 11 species) exhibited an increase in their habitat over the 3GL (Figure 3; Figure S1).

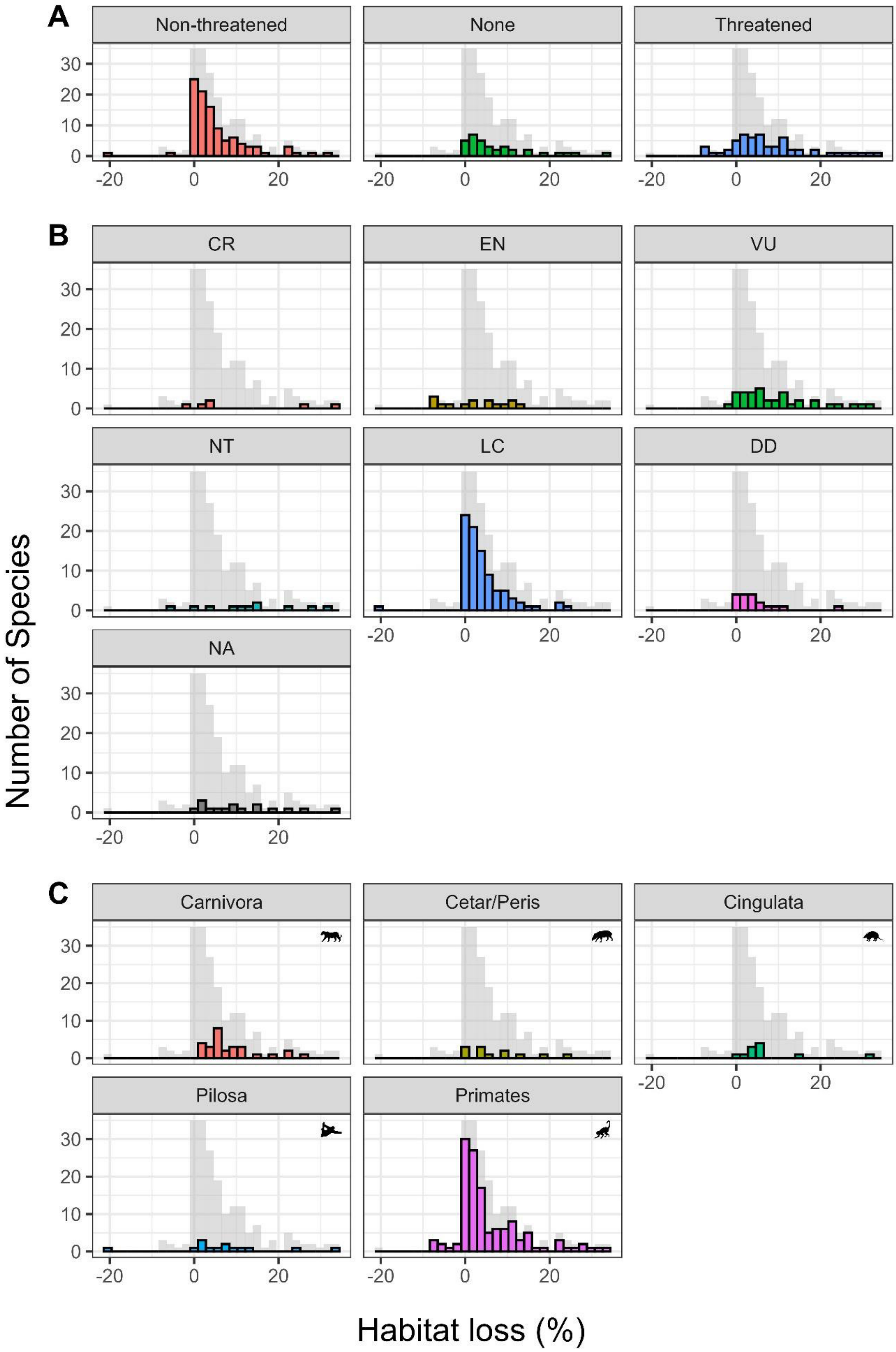


Figure 3: Histograms showing the distribution of habitat loss for the three main classes analyzed (according to described in the methods section): A) Per Conservation Status; B)

Per Conservation Category; and C) per Order. The gray background histogram represents the distribution frequencies of habitat loss for all taxa together. Cetar/Peris indicates the Cetartiodactyla and Perissodactyla orders, respectively.

4 Discussion

Our results revealed that many mammal taxa suffered habitat losses – to different degrees and intensities over the three past generations – while only a few species experienced habitat gains. Highlighting the pervasive effects of habitat loss on species distribution and potential effects on taxa's persistence, already presented in many studies (Crooks et al., 2017; Heinrichs et al., 2016). Overall, habitat loss occurred regardless of Conservation Category, suggesting that some of the current Non-threatened or Not-evaluated species might experience an upgrade in the category in the following extinction risk assessment, solely based on these habitat loss analyses and inferring a consequent proportional population reduction. For example, *Tolypeutes matacus*, the southern three-banded armadillo, nowadays classified as NT, may suffer an *uplisting* (change to a higher threaten category) due to the high habitat loss estimated for its range. The species only inhabits the Pantanal biome, which went through severe wildfires in the past two years (2019-2020), compromising important refugees for this species (Silva et al., 2020).

Species that were recently described but not yet evaluated, may also directly enter the list as threatened when first assessed. One of such examples is the *Cyclopes rufus*, described only five years ago (Miranda et al., 2017), which may be classified as Vulnerable since habitat loss within its range was estimated to be greater than 30% (Table S2). The species lives in one of Brazil's most heavily deforested areas – the Arc of Deforestation in the Amazon, responsible for about 75% of all the habitat loss that the Amazon region has suffered so far (ISA, 2019; Oviedo et al., 2019). Similarly, considering the estimated habitat loss from this study, the recent-described *Leopardus munoai* and *Plecturocebus grovesi* may be classified as NT or threatened in the following extinction risk assessment (Table S2).

Our results demonstrated that habitat loss also affects taxa already categorized as threatened. Nevertheless, even being categorized as threatened, the vast majority lost only a moderate amount of their habitats. This may be due to taxa that had undergone habitat loss too many years ago (before the 3GL time window needed for the application of Criterion A) but has suffered secondary effects of habitat loss and might have been categorized as threatened under another criterion. Such as taxa inhabiting the Atlantic Forest, which has already lost more than 80% of its forests (Fundação SOS Mata Atlântica, 2021), besides being protected by specific regulations Law (Atlantic Forest Law, nº 11.428, December 22, 2006). Also, some taxa may be categorized as threatened because of other factors, such as population reduction due to pathogens, competitors, human conflicts, pollutants, or parasites, or even due to small geographic range or population size along with other threats like population decline. In such cases, habitat loss might be only one of the threats leading to the categorization. Indeed, for many taxa, habitat loss estimation must be accompanied by other types of data, such as population size reductions observed, estimated, or inferred by other sources - such as roadkill and poaching estimates, potential levels of exploitation, number of locations, among other (IUCN, 2019). Furthermore, most of these threatened taxa are contemplated by National Action Plans, which may be mitigating direct threats to the taxa.

Carnivora order underwent the higher habitat loss (Figure 3C). This group is composed predominantly of predator species, with low population densities and high space requirements. Therefore, the order is one of the most threatened in Brazilian territory (Chiarello et al., 2018). After Carnivora, the Cetartiodicatyla and Perissodactyla orders, which compose the ungulates group, seconded the intensity of habitat loss (Figure

3C). These taxa include susceptible species with low reproduction, extended parental care, and high requirements for natural areas (Beca et al., 2017; Jorge et al., 2021; Keuroghlian et al., 2004).

In general, taxa from the Amazon and Cerrado biomes possibly suffered the higher habitat losses. The Amazon still concentrates a high proportion of natural remnants; however, it has lost more than 74 billion hectares of its forest habitats since 1985 (MapBiomas, 2021). The Cerrado, a hotspot in Brazil, has already lost more than 50% of its territory (WWF-Brasil, 2022). The lack of specific legislation, as in the Atlantic Forest, exacerbates the degradation of both biomes, which is projected to continue in the future (Soterroni et al., 2019; Strassburg et al., 2017; Velazco et al., 2019). On the contrary, all taxa that have experienced a habitat expansion in their range inhabit the Atlantic Forest (Table S2; Figure S1). Over the past few years, the biome has witnessed an increase in its natural areas (Rezende et al., 2015; Santos et al., 2012), in part due to specific environmental laws, social-economic shifts, and conservation pacts (Baptista and Rudel, 2006; Fundação SOS Mata Atlântica, 2021)

4.1 – Implications for conservation and management

The data generated from our habitat loss calculation script will undoubtedly support the following assessment of terrestrial mammal taxa in Brazil. Aside from supporting extinction risk assessments, the results from our open data framework may present other implications for conservation. The raster files generated may be post-processed to identify the geometrics patterns of habitat loss (Figure S2; Figure S3). Maurano et al. (2019), analyzing deforestation data from PRODES (2016), identified deforestation patterns with distinct levels of complexity, from which can be observed in this study for Amazonian species: diffuse, linear, regular geometric, multidirectional, herringbone and consolidated, the last three being more complex than the firsts. These different patterns are related to distinct patterns of anthropic occupation and, consequently, will have different effects on species (Maurano et al., 2019). Similarly, with the raster files from this method, it is possible to quickly understand the importance of Protected Areas and Indigenous territories to safeguard biodiversity (Figure S4).

In addition, the information generated can be a robust and important aid for the elaboration and implementation of Conservation Action Plans. The ICMBio also coordinates the National Actions Plans for Conservation - which focus on conservation strategies for threatened species and contemplate the near-threatened ones. These plans are public policies constructed and agreed upon by diverse stakeholders that identify and guide priority actions to reverse threats to wildlife populations and environments, to ensure their survival (Normative Instruction 21/2018). Therefore, our results may assist in identifying critical and priority areas for protection and restoration, thus directing efforts to avoid habitat loss expansion or minimize the effects of habitat loss on threatened species persistence through actions on law enforcement, protected areas, habitat connectivity and enrichment, population management, conservation, education, among others.

The IUCN Red List website (IUCN Red List of Threatened Species) counts with guidelines, tools, and spatial data that assessors may apply to map species ranges. Many of these tools are developed into proprietary software and run locally into the user's machine. Thus, using our script in the GEE platform as a new tool for estimating habitat loss could facilitate spatial analysis in Brazilian national assessment workshops and even for other South American countries or global assessments. We anticipate this open data framework have the potential to qualify the evaluation process in different regions further because it is fast processing, free to academic and research access, and does not require local computer memory or higher processing requirements (Arruda et al., 2021; Gorelick et al., 2017; Souza et al., 2020).

Specialists have improved the extinction risk assessment of biodiversity. However, many taxa still lack essential biological or long-term studies to subsidize population reduction estimation directly. Therefore, its assessments often have to be based on poorly scientifically founded best guesses. The use of new spatial cloud-based technologies can help improve assessments and, ultimately, support decision-making for biodiversity conservation. This approach does not replace direct observations about habitat loss's impacts on wildlife populations (e.g., Tomas et al., 2021). On the other hand, it offers complementary tools, often more widely and quickly applicable, to help understand how much and where habitat loss affects different species and distinct groups of species. Furthermore, this is especially important to improve the conservation assessment processes and establish and implement more efficient conservation measures, mainly when rapid responses are required, and limited resources are available.

In conclusion, the habitat loss analysis approach we presented here qualified the Conservation Status assessment process for terrestrial mammals in Brazil, bringing new information to guide research and conservation efforts. Moreover, it can be directly applied or adapted for use in other similar assessments while remaining open to continuous development.

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```
1   users/maributti/HabitatMammalsBR/function.js
2
3   /* Function created by Mariella Butti v.1
4
5   Default code runs with MapBiomas Brazil.
6   Another initiative migth be selected at the lines 49 to 54.
7
8   */
9
10  exports.HabitatLoss = function(
11                  sp_name,
12                  sp_area,
13                  alt_ini,
14                  alt_fin,
15                  ano_ini,
16                  ano_fin,
17                  habitat,
18                  scale,
19                  folder_name,
20                  results_format){
21    /* Where:
22    sp_name - string
23    sp_area - polygon
24    habitat - list
25    alt_ini - integer
26    alt_fin - integer
27    ano_ini - integer between 1985 and 2020
28    ano_fin - integer between 1985 and 2020
29    scale - integer
30    folder_name - string
31    results_format - "CSV" or "SHP"
32   */
33
34  //////////////////////////////////////
35  /////////////// CODE ////////////////
36  //////////////////////////////////////
37
38  // Create ee.FeatureCollection
39  //Criar obejto do tipo ee.FeatureCollection
40   sp_area = ee.FeatureCollection(sp_area)
41
42  // Create ee.List
43  //Criar objeto do tipo ee.List
44   habitat = ee.List(habitat)
45
46  // Select SRTM altitudinal range
47  //Selecionar a amplitude altimétrica da base SRTM
48  var srtm = ee.Image("CGIAR/SRTM90_V4");
49      srtm = srtm.expression("b(0) <" + alt_fin + " & b(0) >" +  alt_ini + "? 1 : 0")
50                 .clip(sp_area)
51
                   //.updateMask(ee.Image('projects/ee-maributti/assets/CVinagre_model30_patc
                   hes_tiff'));
52
53
54  // Call Mapbiomas collection - select the iniciative by comment/uncomment the line
55  //Chamar coleção do Mapbiomas
56  var mapbiomas =
    ee.Image("projects/mapbiomas-workspace/public/collection6/mapbiomas_collection60_integrat
    ion_v1") // Brazil 1985-2020 - Collection 6.0 - Legend code
57  //var mapbiomas =
    ee.Image("projects/mapbiomas-raisg/public/collection3/mapbiomas_raisg_panamazonia_collect
    ion3_integration_v2") // Panamazonia 1985-2020 - Colection 3.0 - Legend code
    https://s3.amazonaws.com/amazonia.mapbiomas.org/leyenda/C%C3%B3digo_de_la_Leyenda_-_colec
    ci%C3%B3n_3.pdf
58  //var mapbiomas =
    ee.Image("projects/mapbiomas-chaco/public/collection2/mapbiomas_chaco_collection2_integra
    tion_v1") // Chaco - Collection 2.0 - Legend code
    https://mapbiomas-br-site.s3.amazonaws.com/Legenda/leyenda_mbchaco_col2_detallada__ES_.pd
```

```
f
//var mapbiomas = ee.Image("projects/MapBiomas_Pampa/public/collection1/mapbiomas_pampa_collection1_integration_v1") // Pampa 2000-2019 - Collection 1.0 - Legend code https://mapbiomas-tri-pampa-site.s3.amazonaws.com/_ENG__Legend_Codes_Collection_1_PAMPA.pdf
//var mapbiomas = ee.Image("projects/mapbiomas_af_trinacional/public/collection1/mapbiomas_atlantic_forest_collection1_integration_v1") // Atlantic Forest 2000-2019 - Collection 1.0 - Legend code https://mapbiomas-tri-mataatlantica-site.s3.amazonaws.com/LEGEND_CODES-AF.pdf
//var mapbiomas = ee.Image("projects/mapbiomas-indonesia/public/collection1/post_Integration_filter_rev_2_10_3") //Indonesia 2000-2019 - Colection 1.0 - Legend code: https://mapbiomas.nusantara.earth/assets/files/Kode%20Legenda%20-%20Legend%20Code.pdf
                .clip(sp_area);

// Select Mapbiomas data for each year and mask within specified elevation range
//Selecionar os rasters de acordo com os anos e criar uma image collection apenas com os anos da janela de analise e apenas do range altimetrico selecionado
var ini= mapbiomas.select("classification_"+ ano_ini)
                  .updateMask(srtm);

var fim = mapbiomas.select("classification_"+ ano_fin)
                   .updateMask(srtm);

// Remap habitat and non-habitat values to 1 and 0
//Reclassificar as imagens para os valores de 0-1 em classes de habitat/nao-habitat
var remapped_ini= ini.remap(habitat,ee.List.repeat(1,habitat.length()),0);
var remapped_fin = fim.remap(habitat,ee.List.repeat(1,habitat.length()),0);


// Calculate last year habitat area in square kilometers
//Calcular área final de habitat em km2
var areafim = remapped_fin.multiply(ee.Image.pixelArea());
 areafim = areafim.reduceRegion({
  reducer: ee.Reducer.sum(),
  geometry: sp_area,
  scale:scale, //Set to 2000 to AOO calculations
  maxPixels:1e16
});

// Calculate first year area in square kilometers
//Calcular área inicial de habitat em km2
var areaini = remapped_ini.multiply(ee.Image.pixelArea());
 areaini = areaini.reduceRegion({
  reducer: ee.Reducer.sum(),
  geometry: sp_area,
  scale:scale,
  maxPixels:1e16
});

// Calculate loss percentage
//Calcula a porcentagem de perda de área
var loss_perc = ee.Number(ee.Number(1).subtract(ee.Number(areafim.get('remapped')).divide(ee.Number(areaini.get('remapped'))))).multiply(ee.Number(100));

// Create results Object
//Cria um objeto para receber todos os resultados
var results = ee.Dictionary.fromLists({keys:
                                        ["Species",
                                        "Scale",
                                        "First_year",
                                        "Last_year",
                                        "Lower_elev",
                                        "Higher_elev",
                                        "Habitat_classes",
                                        "FY_sqkm",
                                        "LY_sqkm",
```

```
                                        "Perc_loss"],
                                        values:
                                          [sp_name,
                                          scale+" meters",
                                          ano_ini,
                                          ano_fin,
                                          alt_ini,
                                          alt_fin,
                                          ee.String.encodeJSON(habitat),
                                          ee.Number(areaini.get('remapped')).divide(1e6),
                                          ee.Number(areafim.get('remapped')).divide(1e6),
                                          ee.Number(loss_perc)]})


// Print summary results
//Mostrar resultados no console
print("Habitat Loss", results)

//Plot maps//

// First Year Habitat Classification Map
//habitat no primeiro ano
Map.addLayer(remapped_ini,{palette:["ffffff","ffb40c"]},"First Year habitat")

// Last Year Habitat Classification Map
//habitat no último ano
Map.addLayer(remapped_fin,{palette:["ffffff","a90505"]},"Last Year habitat")

// Elevation selected range
//Elevação adequada
Map.addLayer(srtm,{palette:["ffffff","893fff"]},"Elevation selected");

//Exports//

// Export FY map as rasters
//Exportar mapa do ano inicial
Export.image.toDrive({image:remapped_ini,
                      description:sp_name+"First_year_habitat",
                      folder:sp_name,
                      fileNamePrefix: sp_name+ano_ini,
                      region:sp_area,
                      scale:scale, //Set to 2000 to AOO calculations
                      maxPixels: 1e13});

// Export LY map as rasters
//Exportar mapa do ano final
Export.image.toDrive({image:remapped_fin,
                      description:sp_name+"Last_year_habitat",
                      folder:sp_name,
                      fileNamePrefix: sp_name+ano_fin,
                      region: sp_area,
                      scale:scale, //Set to 2000 to AOO calculations
                      maxPixels: 1e13});

// Export results table as CSV or SHP
//Exportar tabela de resultados em formato CSV ou SHP
Export.table.toDrive({collection:
ee.FeatureCollection([ee.Feature(sp_area.geometry(),results)]),
                      description: sp_name+"habitat_results",
                      folder:sp_name,
                      fileNamePrefix: "Habitat_"+sp_name,
                      fileFormat: results_format
                      })

return(results, remapped_ini, remapped_fin, srtm)

} //END//

////////////////////////////////////////////////////////////////////////////////////////
```

```
////////////////////

users/maributti/HabitatMammalsBR/HabitatLoss_fromAsset

/**
 * @description
 *    Calculates and compares two years habitat areas from classes id, time window, elevation range and especies distribution polygon
 * @author
 *    Mariella Butti
 */

// Create the variables
var sp_name = "Sp_species" /// Species name without spaces
var alt_ini = -1000 // lower altitude of the species distribution
var alt_fin = 3000 // higher altitude of the species distribution
var ano_ini = 1985 // fist year - starts in 1985
var ano_fin = 2020 // last year - until 2020
var scale = 30 // spatial scale in meters
var habitat = [3] // legend code according to https://mapbiomas-br-site.s3.amazonaws.com/_PT-BR__C%C3%B3digos_da_legenda_Cole%C3%A7%C3%A3o_6.pdf
var folder_name = sp_name+scale
var results_format= "CSV"

// Create AOI from your asset
var shape = ee.FeatureCollection("users/YOURUSERNAME/ASSET"); //distribution area polygon from asset
Map.addLayer(shape, {},  "distribution area")

// Call the function from another script
var funcoes = require("users/maributti/HabitatMammalsBR:function.js")

/// Running functions
var teste = funcoes.HabitatLoss(
                sp_name,
                shape,
                alt_ini,
                alt_fin,
                ano_ini,
                ano_fin,
                habitat,
                scale,
                folder_name,
                results_format
                )

 //END//

//////////////////////////////////////////////////////////////////////////////////////////////////////////////

users/maributti/HabitatMammalsBR/HabitatLoss_fromRaster

/**
 * @description
 *    Calculates and compares two years habitat areas from classes id, time window, elevation range and especies distribution polygon
 * @author
 *    Mariella Butti
 */

// Call distribution area from raster asset
var image = ee.Image('YOUR/ASSET/RASTER')

// Create the variables
var sp_name = "Sp_species" /// Species name - without spaces
var alt_ini = -1000 // lower altitude of the species distribution
```

```
var alt_fin = 3000 // higher altitude of the species distribution
var ano_ini =  2005 // fist year - starts in 1985
var ano_fin = 2020 // last year - until 2020
var scale = 30// spatial scale in meters
var habitat = [4,12,13] // legend code according to https://mapbiomas-br-site.s3.amazonaws.com/_PT-BR__C%C3%B3digos_da_legenda_Cole%C3%A7%C3%A3o_6.pdf
var folder_name = sp_name+scale
var results_format= "CSV"

// Create AOI from raster asset
var shape = image.divide(image).toInt().reduceToVectors({maxPixels:1e12})
Map.addLayer(shape, {},  "distribution area")

// Call the function from another script
var funcoes = require("users/maributti/HabitatMammalsBR:function.js")

/// Running functions
var teste = funcoes.HabitatLoss(
                sp_name,
                shape,
                alt_ini,
                alt_fin,
                ano_ini,
                ano_fin,
                habitat,
                scale,
                folder_name,
                results_format
                )

 //END//

//////////////////////////////////////////////////////////////////////////////////////////////////////////////

users/maributti/HabitatMammalsBR/HabitatLoss_FreeHandPoly

/**
 * @description
 *    Calculates and compares two years habitat areas from classes id, time window, elevation range and especies distribution polygon
 * @author
 *    Mariella Butti
 */

// Create the variables
var sp_name = "Sp_especies" /// Species name - without spaces
var alt_ini = -1000 // lower altitude of the species distribution
var alt_fin = 3000 // higher altitude of the species distribution
var ano_ini = 1985 // fist year - starts in 1985
var ano_fin = 2020 // last year - until 2020
var scale = 30 // spatial scale in meters
var habitat = [3] // legend code according to https://mapbiomas-br-site.s3.amazonaws.com/_PT-BR__C%C3%B3digos_da_legenda_Cole%C3%A7%C3%A3o_6.pdf
var folder_name = sp_name+scale
var results_format= "CSV"

// Create AOI from draw or from asset
var shape = ee.FeatureCollection(geometry); // distribution area from map polygon
Map.addLayer(shape, {},  "distribution area")

// Call the function from another script
var funcoes = require("users/maributti/HabitatMammalsBR:function.js")

/// Running functions
var teste = funcoes.HabitatLoss(
                sp_name,
```

```
                shape,
                alt_ini,
                alt_fin,
                ano_ini,
                ano_fin,
                habitat,
                scale,
                folder_name,
                results_format
                )

 //END//
//////////////////////////////////////////////////////////////////////////////////////////
////////////////////
```