PROGRESS REPORT II

PROJECT: **Are neotropical treefrogs ecologically labile? The use of information on the evolutionary behavior of niches in access to the impacts of climate change.**

APPLICATION: **27629-2**

LEADER: **Lucas Nicioli Bandeira**

1 – Summary of activities in the period.

ACTIVITY	LOCAL	PERIOD	CITY, STATE	COUNTRY
#1 Achievement of climatic profiles	**LABECA - INPA**	**11/01 – 11/02/2020**	**Manaus, AM**	**Brazil**
#2 Conversion of ENM's to SDM's	**LABECA - INPA**	**12/02 – 12/03/2020**	**Manaus, AM**	**Brazil**
#3 Projection of models for different time periods	**LABECA - INPA**	**12/03 – 12/05/2020**	**Manaus, AM**	**Brazil**
#4 What is protected?	**LABECA - INPA**	**12/03 – 12/05/2020**	**Manaus, AM**	**Brazil**
#5 Performing descriptive analyses	**Home (World Health Organization recommendation)**	**13/05 - Now**	**Goiânia, GO**	**Brazil**

2 – Description of activities.

Seeking a better understanding of the steps by the reviewers, this presentation will follow the subdivisions: (1) Achievement of climatic profiles, (2) Conversion of Ecological niche models – ENM's to Species distribution models – SDM's, (3) Projections, (4) What is protected? and, (5) Performing descriptive analyses.

(1) To access the climatic niche preferences, we constructed density plots for each species with the frequency values for 22 climatic variables using the *sm* package in R (plots in section 3.1 below). The use of density estimates is an effective way of summarizing the climatic profile of each species (or Profile Niche Occupancy – PNO's), a reliable way to access patterns of climatic niche similarities and differences between species and, by comparing frequencies through time, highlighting, at least in general, how the niches evolved (i.e., remaining conserved or diverging from the ancestral niche).

In (2) and (3), we modelled the species geographical distribution to estimate its current potential distribution (i.e., the species distribution model, hereafter "SDM") and project it in four periods in the future (Representative Concentration Pathway - RCP 2.6 % and 8.5% for 2050 and 2070, according to IPCC). To this end, the totality of the occurrence records was used for the construction of the distribution models. We used occurrence data for nine *Pithecopus's* species as input data for the subsequent modelling routines. Records were compiled from the herpetological collections and museums. We also checked relevant published articles for complementary records to include records that could unambiguously be assigned to a precise location via provided GPS coordinates. After obtaining, verifying, and validating each occurrence record, our final data set of unique georeferenced records included records with satisfactory geographic coverage of species' known distribution.

For current and future climatic data, we assembled 19 digital layers of climatic variables with continuous data for temperature and precipitation that are closely related to ecological and physiological tolerances of anurans. We assembled digital layers of environmental variables with continuous data for temperature and precipitation obtained from the "WorldClim Global Climate Data" (*http://worldclim.org/*). We also used three more predictors related to the availability of water in the environment. The first and second layers representing the process of evapotranspiration (*"Potential Evapo-Transpiration - PET"; "Annual Evapo-Tranpiration - AET"*) and the third, *"Aridity Index-AI",* that simulates the high temperature stress (*http://cgiar.community/*).

SDM's were constructed using the maximum entropy algorithm MaxEnt implemented with the KUENM package in R. MaxEnt generates predictions from presence only data, based on the principle of maximum entropy, which assumes that the best approximation for an unknown distribution is one that satisfies any constraint to their distribution. This algorithm became the most adequate and widely used technique for modelling species distributions and, among other advantages, is considered more successful than other methods for generating models from a reduced number of points of occurrence.

The final models were generated using 10 independent replicates, while 50% of the points (k) were used for testing using the Bootstrap method. We chose the logistic output for the presentation of ENM´s in geographic space (potential distributions), with each pixel (geographic cell) representing suitability from 0 (representing inadequate conditions) to 1 (maximum suitability). The performance of the candidate models was evaluated hierarchically using three independent and complementary criteria, namely: significance, predictive ability, and complexity. That is, models were initially filtered to detect those statistically significant; later, the "low-omission criterion" (via Area Under Curve – AUC method) was applicated to further reduce the set of models and finally, among the significant models with the lowest omission rate, those with delta AICc values smaller than two are selected as the best model (s).

To obtain *Pithecopus'* potential distribution models (SDM's) in each of the temporal slices (present plus future), we converted the ecological niche models (suitability maps ranging from 0 to 1) to a presence-absence model (binary maps) using a specific threshold (value of "cut-off") (figures in section 3.2). As highly recommended, for the proposed conversion between SDM's obtained via the application of the Maxent algorithm for SDM's, we chose to use the "Maximum test sensitivity plus specificity - MTS+S" as our threshold. This threshold maximises the cases where the model erroneously assigns unsuitable habitat (true negative) and misses suitable habitat (false positive), taking the risk of overestimating distributions than to miss important habitats.

In (4) we access which areas within the total predicted distribution are effectively protected (here we assume that areas within conservation units are safe). For this purpose, each of the SDM's previously obtained was cut (using the function "clip" in the ArcGis software) based on a surface corresponding to all South American conservation units (i.e., Parks, natural reserves etc.) (downloaded at *www.protectedplanet.net*). As a result of this routine, we obtained maps highlighting which areas are located within these units and therefore, following our premise, protected (see figures in section 3.3).

Finally, in order to provide a more detailed view of our results, enabling a greater understanding of the scenario studied, we have extracted intrinsic information from the distribution models and compiled them in graphs and tables (step “5” in the activity summary table). We decided to divide the information according to the theme and we organized the results in two subsections: “3.4.1 - Variation of the total area predicted as presence in different climatic scenarios” and “3.4.2 – Conservation Units efficiency”. In the first subsection, we basically compile the information from the predicted area (in the specific attribute table of each layer at each time) and organize it in cartesian graphs. In the second subsection, we perform the calculation of the percentage of the protected area according to the following formula:

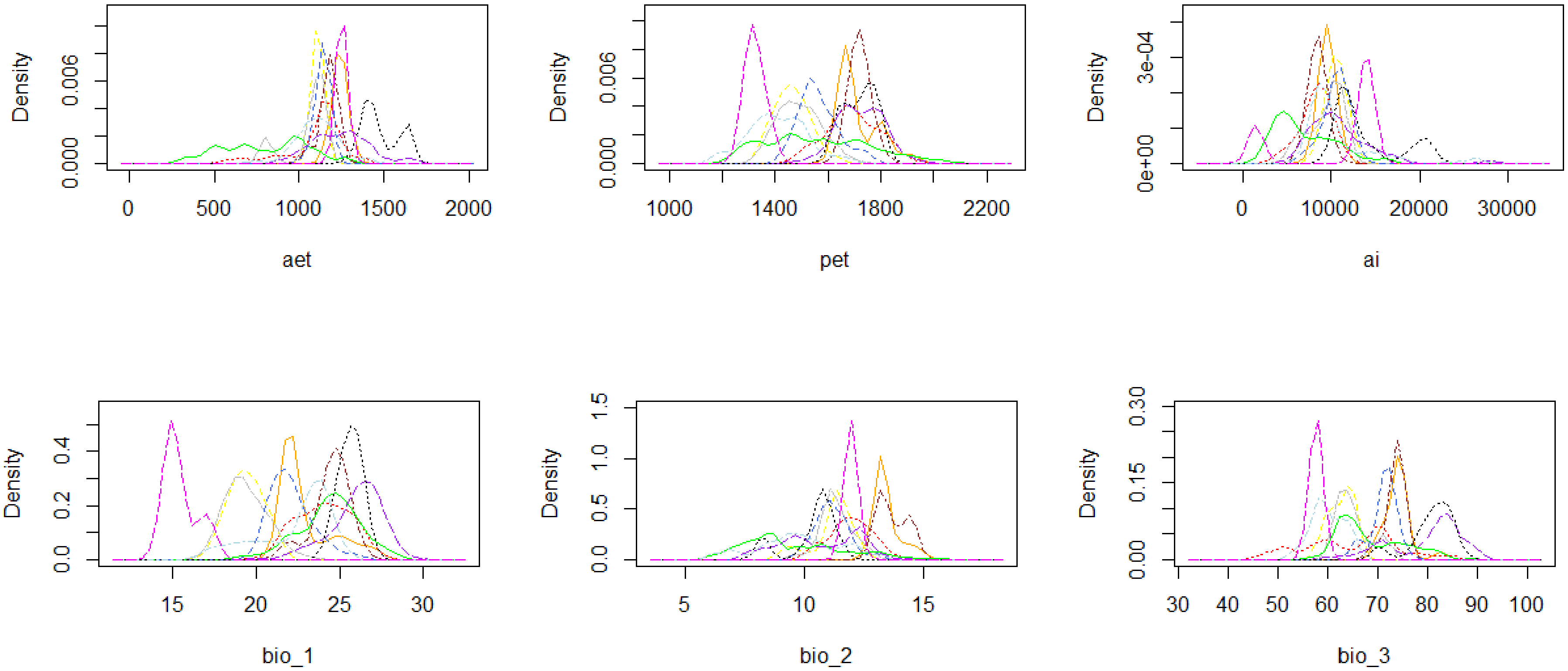
$$E = \frac{UC's\ RANGE}{TOTAL\ DISTRIBUTIONA\ RANGE}$$

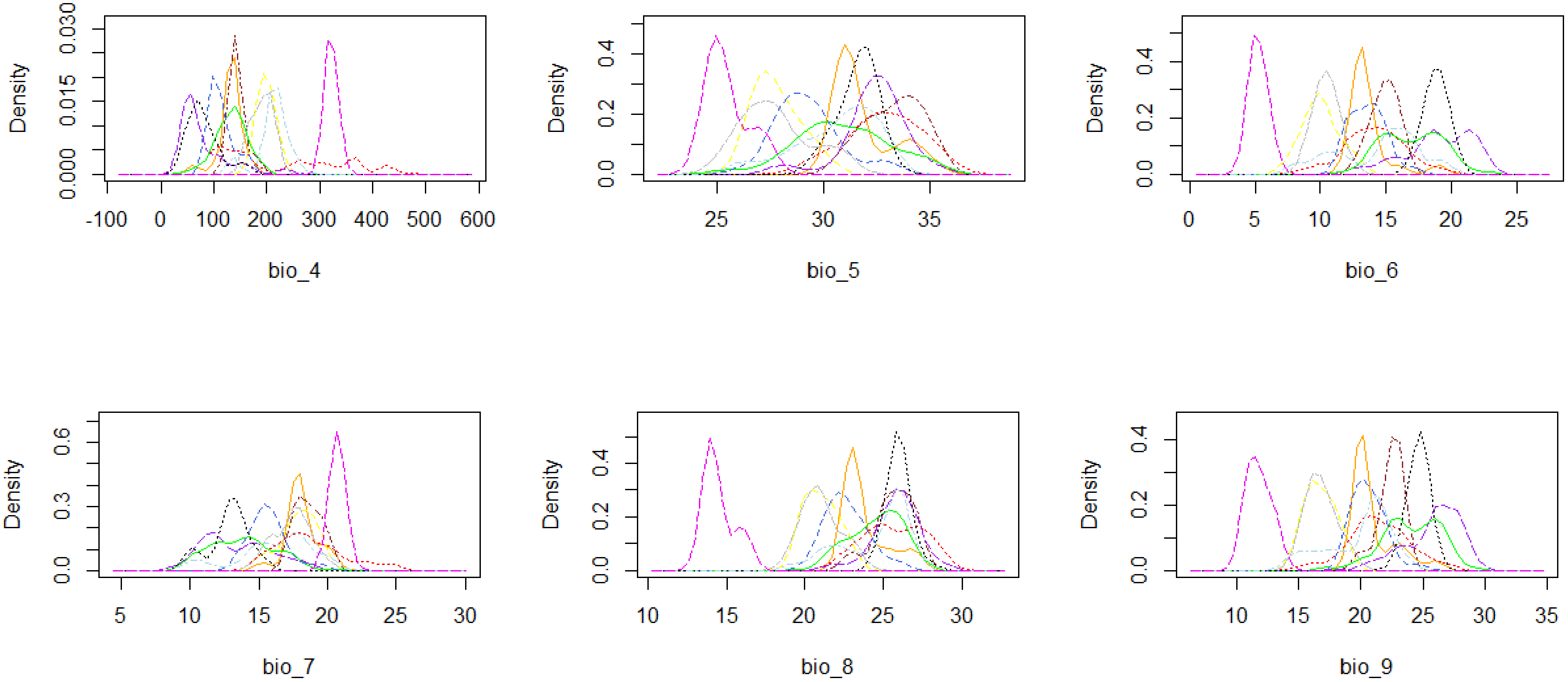
E = UC´s efficiency
UC´s Range = How much of the predicted area occurs within ea of conservation units
Total Distributional range = total area predicted to be occupied

3 – Results.

It is worth noting that given the relevance of the issues addressed by our work (mainly species conservation), the need for increasingly robust models (the base product from which information was used to construct the other results and conclusions), which represent in a most reliable way the phenomena being modeled, has become (and still does) more and more required. Here, using the KUENM package and the newly automation of important modeling routine steps, we tested multiple parameterizations (different configurations of Maxent algorithm elements) which allowed us to present models with high robustness and refinement and the construction of inferences (e.g., about the potential impacts of climate change or the possible speciation mechanisms involved in genus diversification) with high credibility.

3.1 – *Pithecopus*' species climatic profiles or Profile of Niche Occupancy – PNO'S

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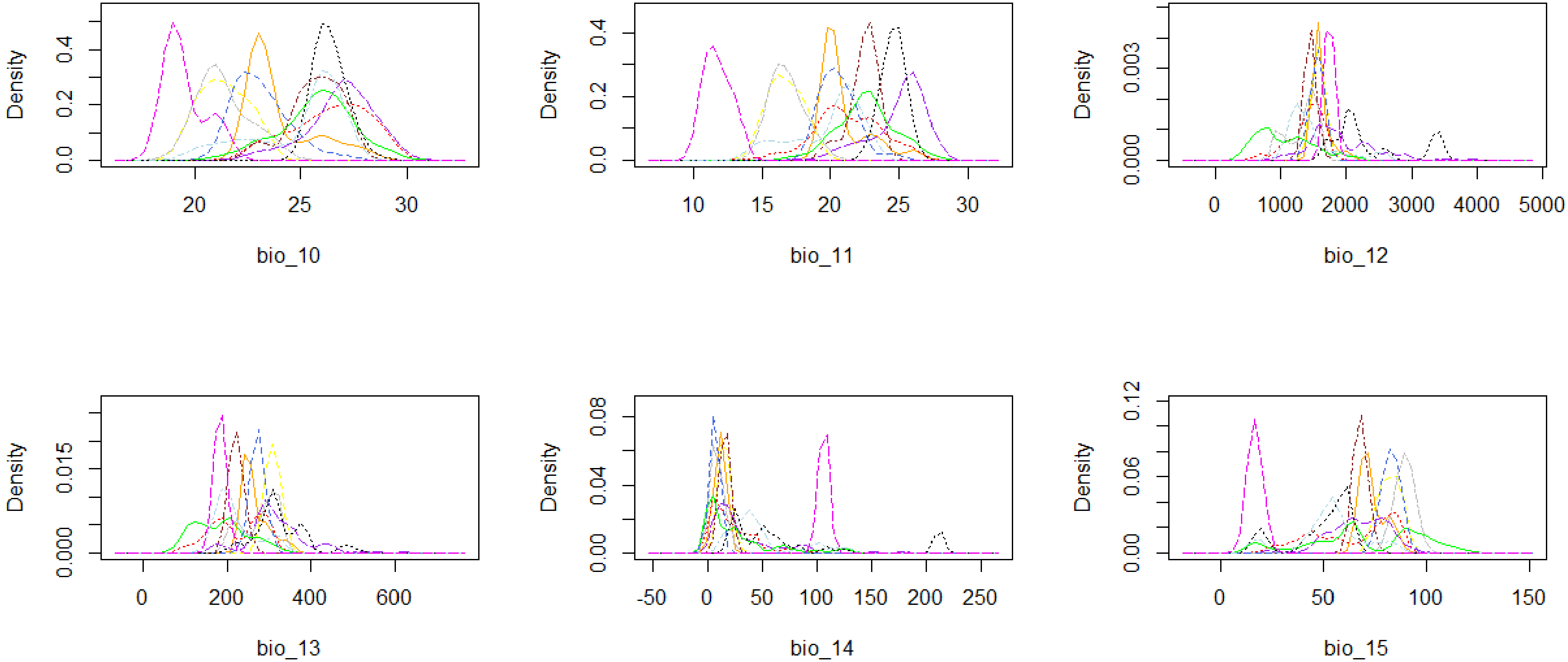
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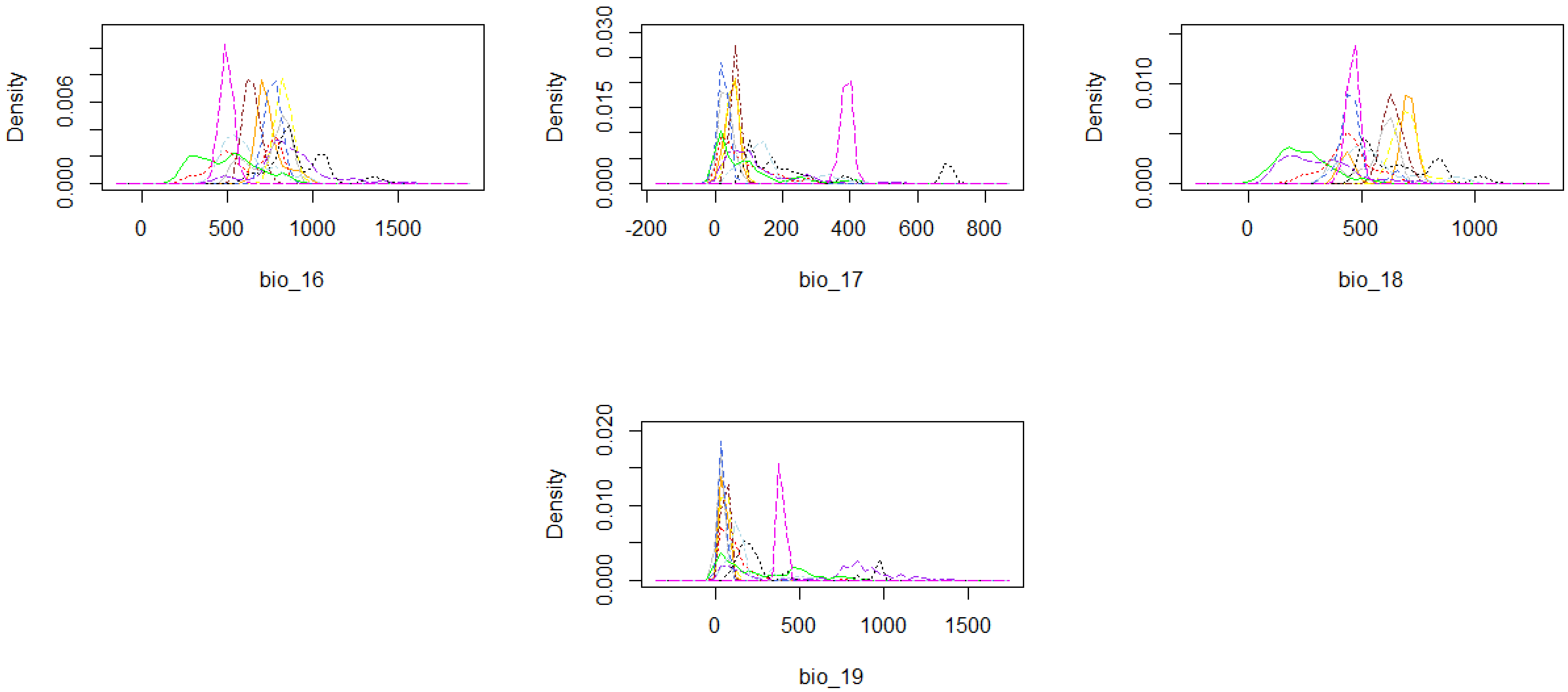

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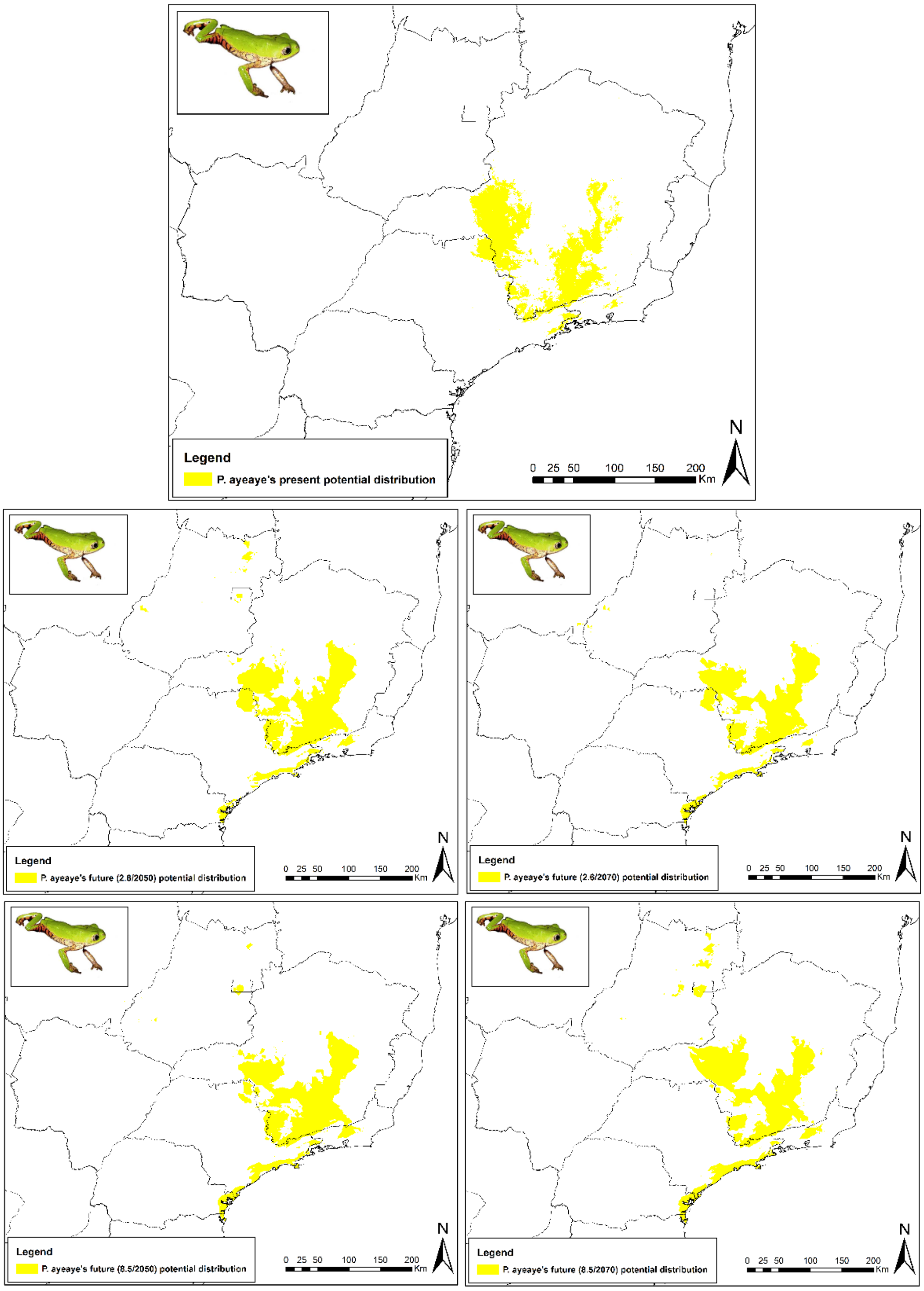
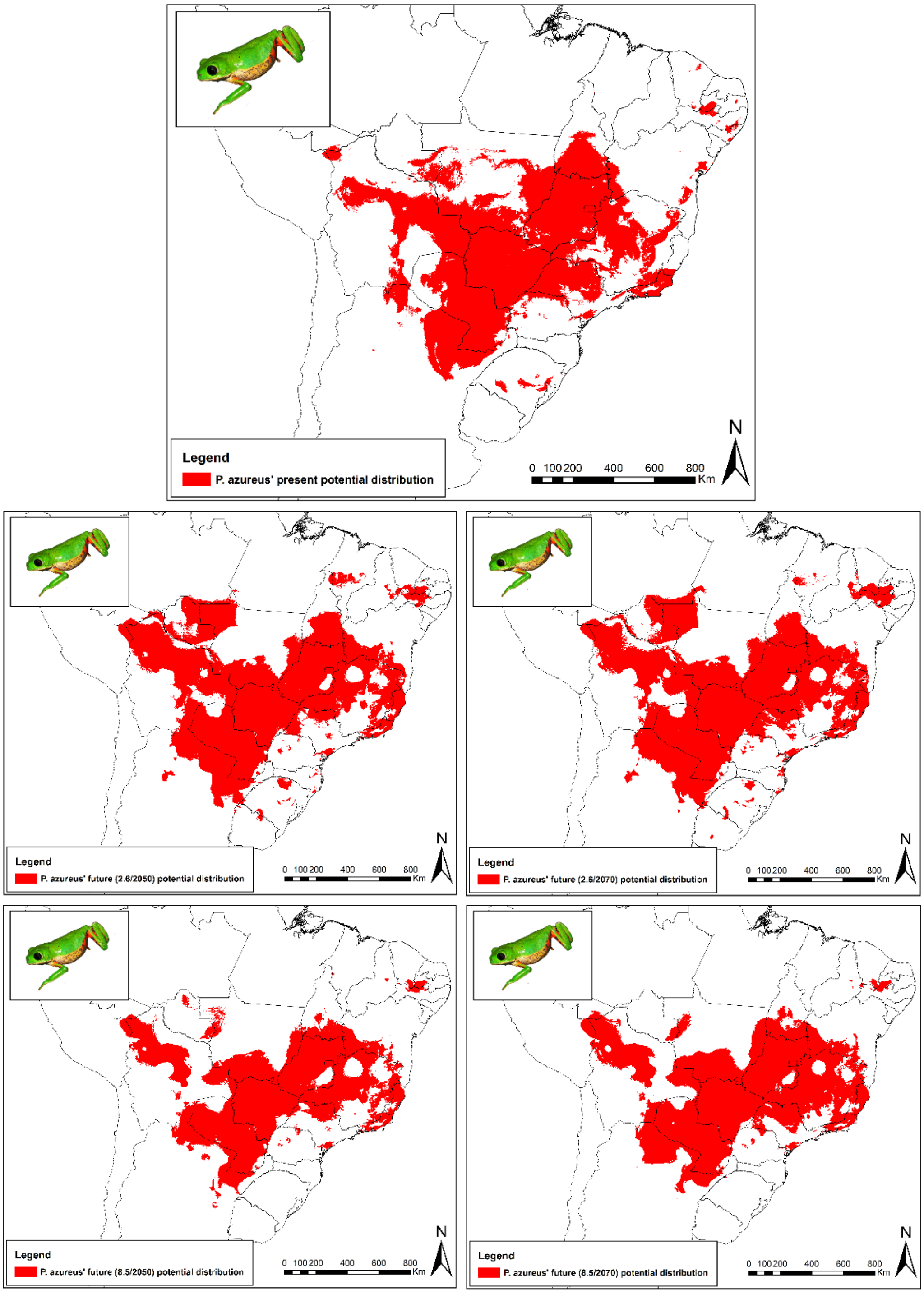
Figure legend: Density comparisons of climatic values for each species of the genus *Pithecopus*. ("bio_1": Annual Mean Temperature; "bio_2": Mean Diurnal Range (Mean of monthly (max temp - min temp)); "bio_3": Isothermality (BIO2/BIO7) (* 100); "bio_4": Temperature Seasonality (standard deviation *100); "bio_5": Max Temperature of Warmest Month; "bio_6": Min Temperature of Coldest Month; "bio_7": Temperature Annual Range (BIO5-BIO6); "bio_8": Mean Temperature of Wettest Quarter; "bio_9": Mean Temperature of Driest Quarter; "bio_10": Mean Temperature of Warmest Quarter; "bio_11": Mean Temperature of Coldest Quarter; "bio_12": Annual Precipitation; "bio_13": Precipitation of Wettest Month; "bio_14": Precipitation of Driest Month; "bio_15": Precipitation Seasonality (Coefficient of Variation); "bio_16": Precipitation of Wettest Quarter; "bio_17": Precipitation of Driest Quarter; "bio_18": Precipitation of Warmest Quarter; "bio_19": Precipitation of Coldest Quarter; "aet": annual evapotranspiration; "pet": potential evapotranspiration and, "ai": aridity index.). (orange = *P. araguaius*; yellow = *P. ayeaye*; red = *P. azureus*; brown = *P. centralis*; purple = *P. hypochondrialis*; gray = *P. megacephalus*; green = *P. nordestinus*; blue = *P. oreades*; black = *P. palliatus*; light blue = *P. rohdei*; and pink = *P. rusticus*).

3.2 – Projections of the best model for the present in different climate scenarios in the future.

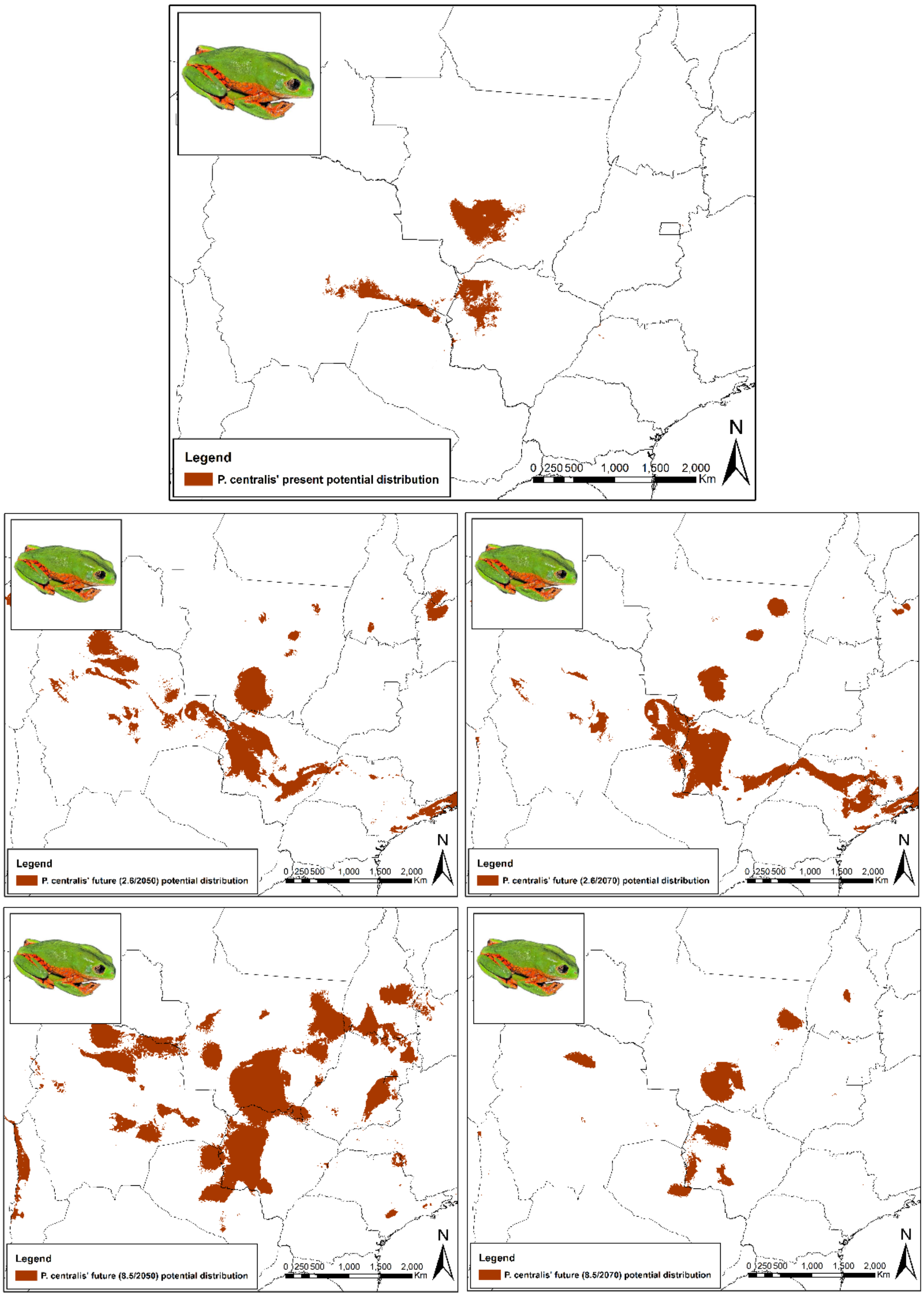
- ***Pithecopus ayeaye***



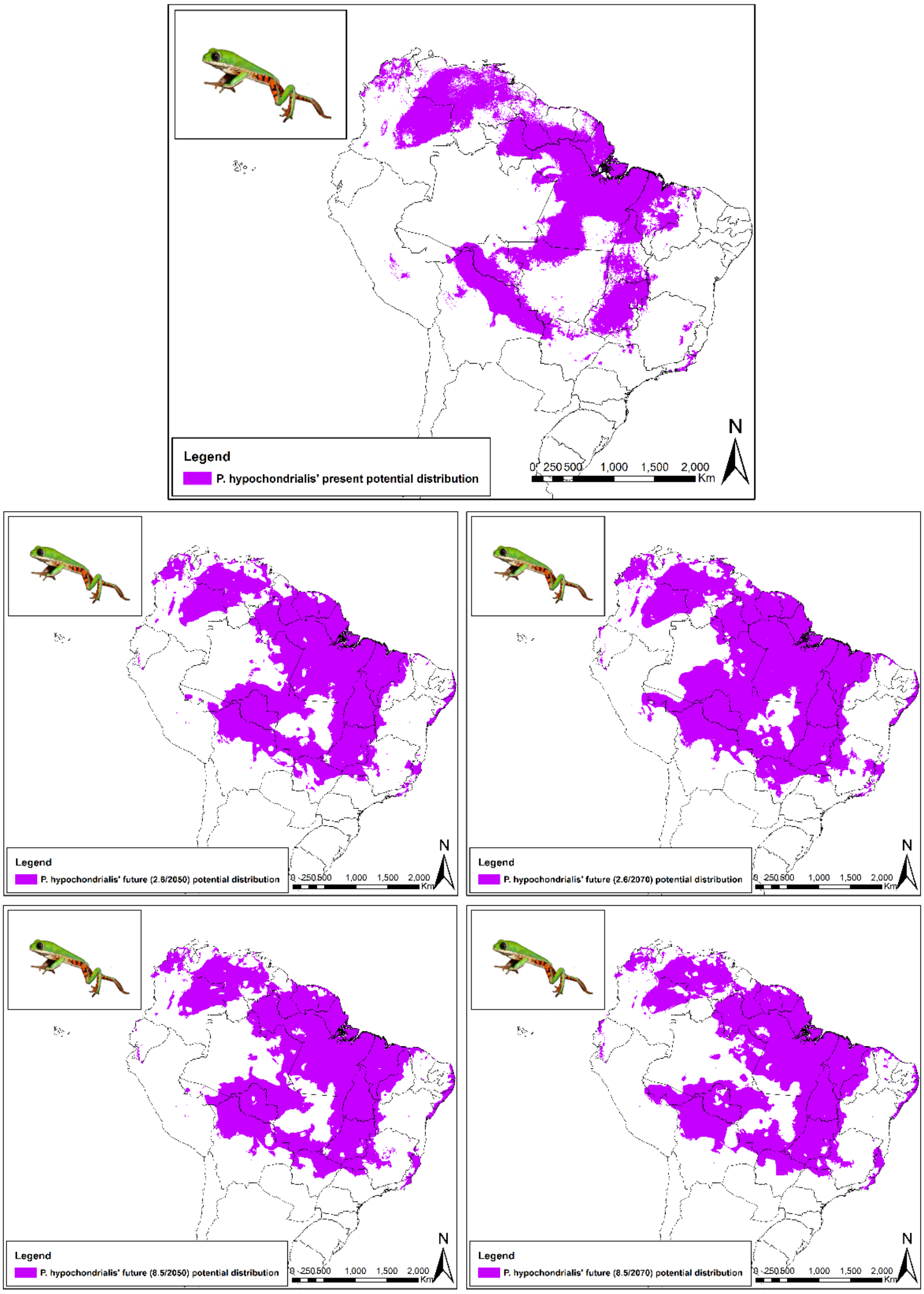
- ***Pithecopus azureus***



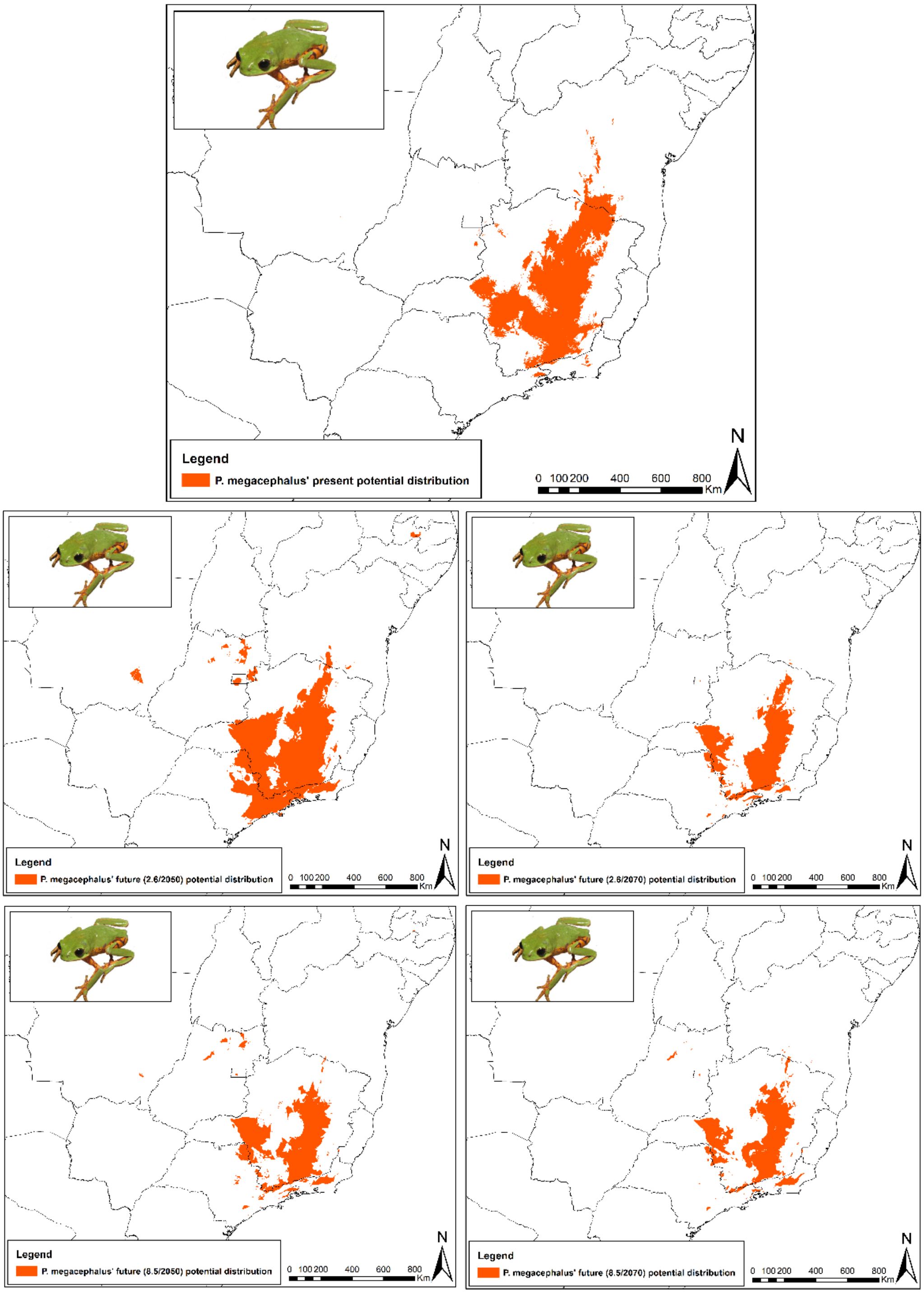
- ***Pithecopus centralis***



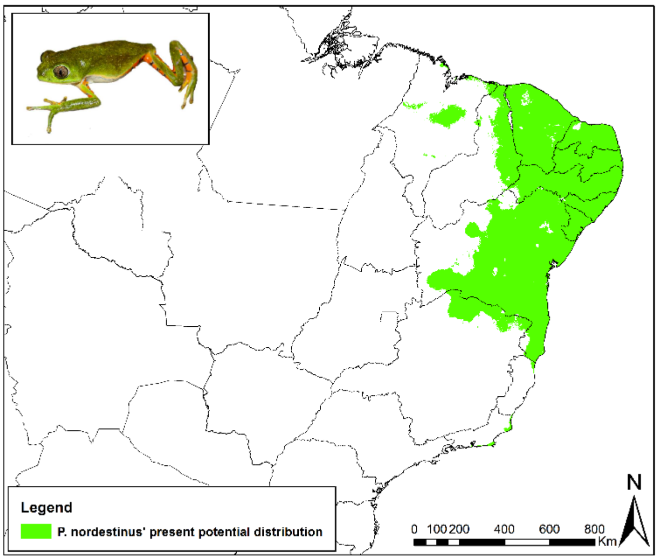
- ***Pithecopus hypochondrialis***

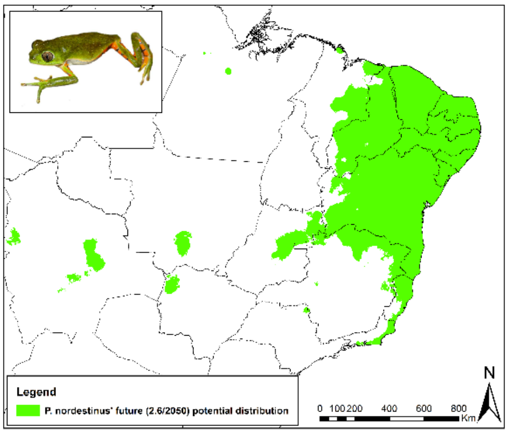


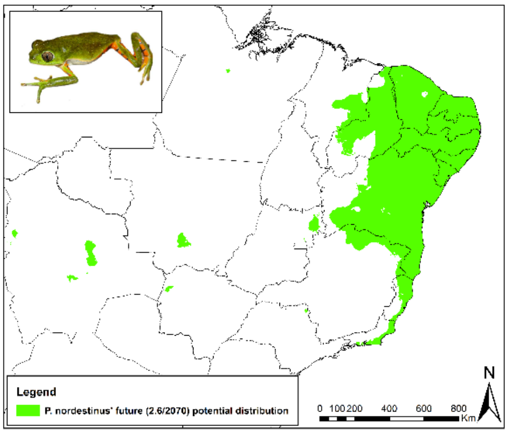
- ***Pithecopus megacephalus***

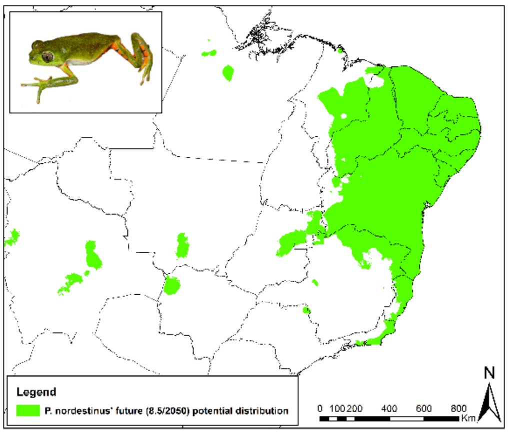


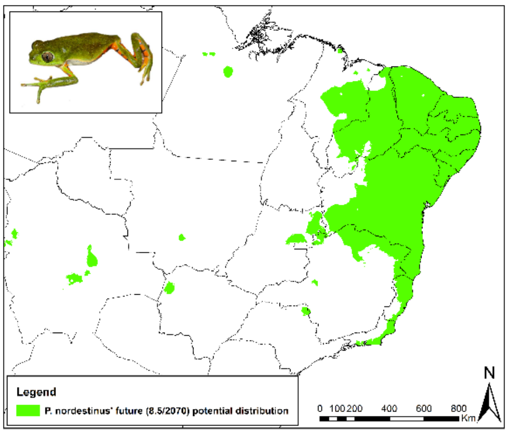
- ***Pithecopus nordestinus***



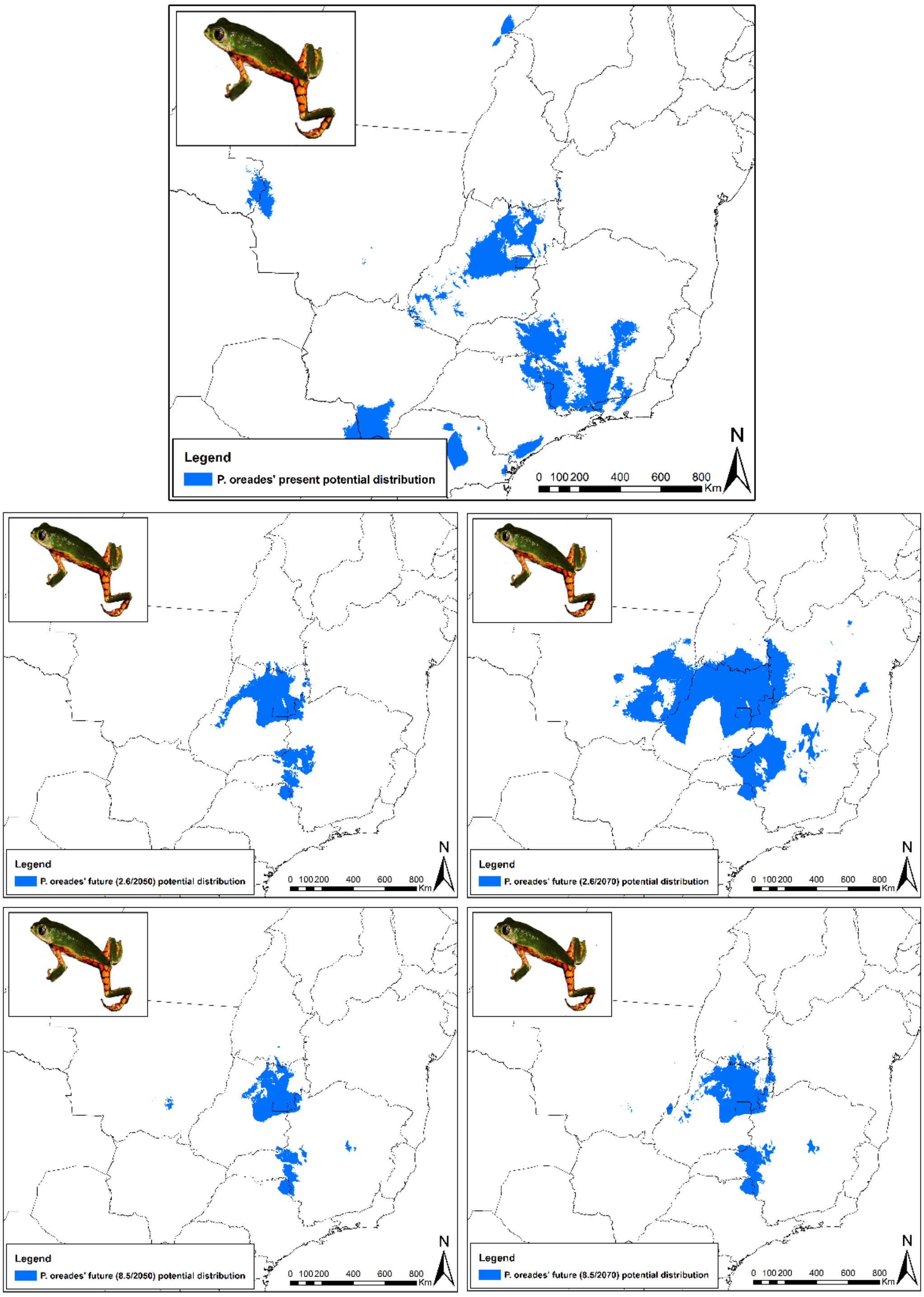




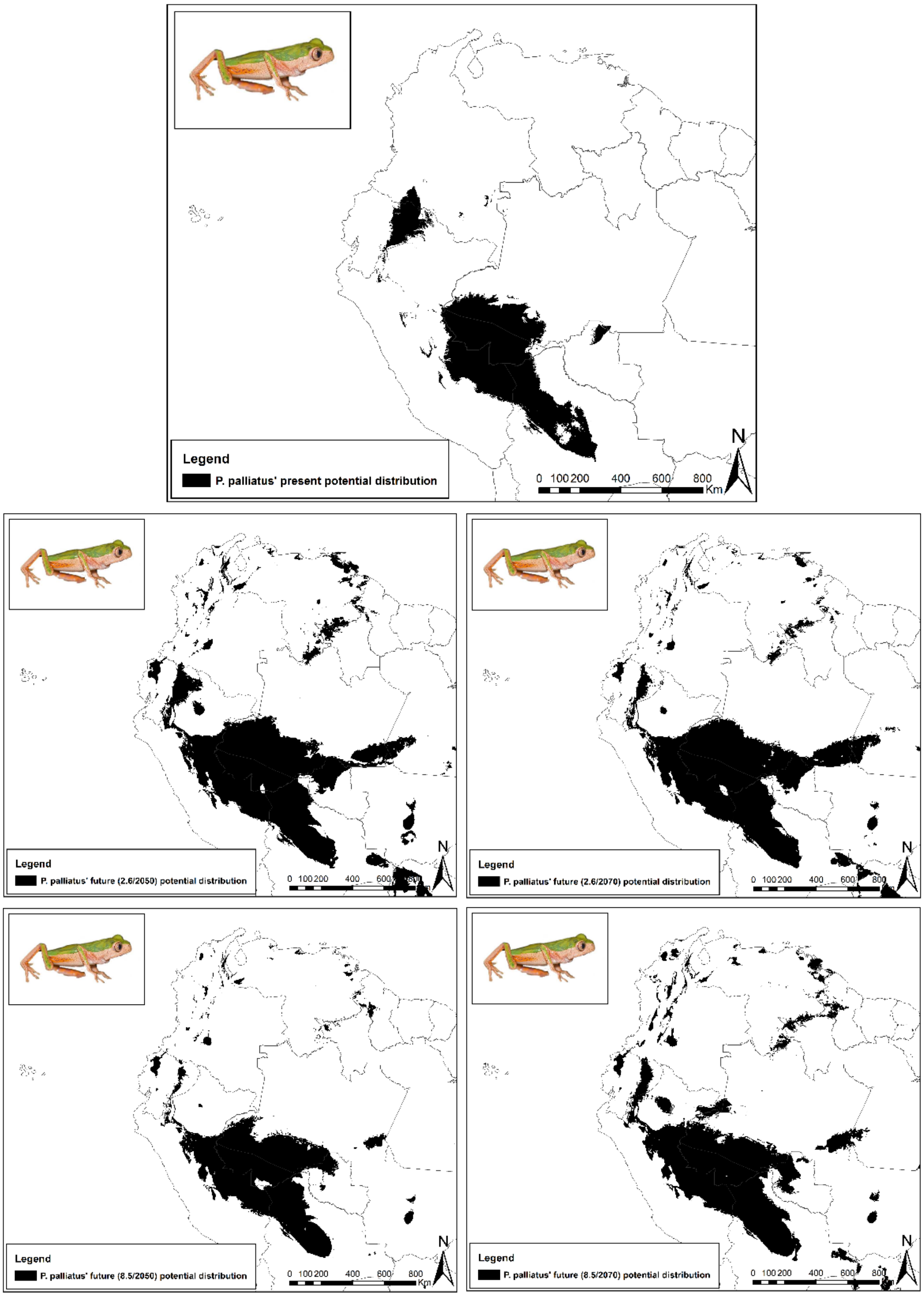




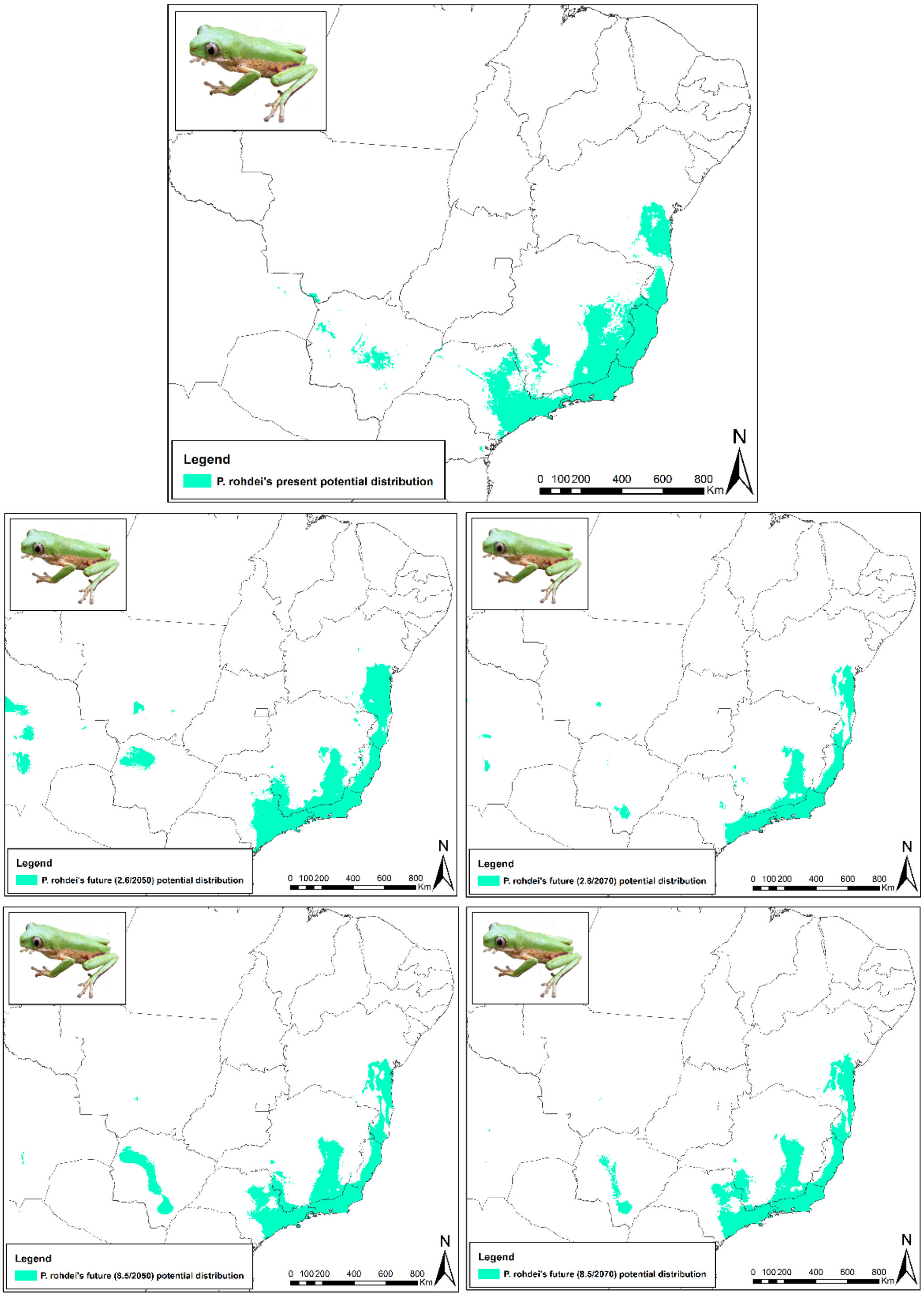
- ***Pithecopus oreades***



- ***Pithecopus palliatus***

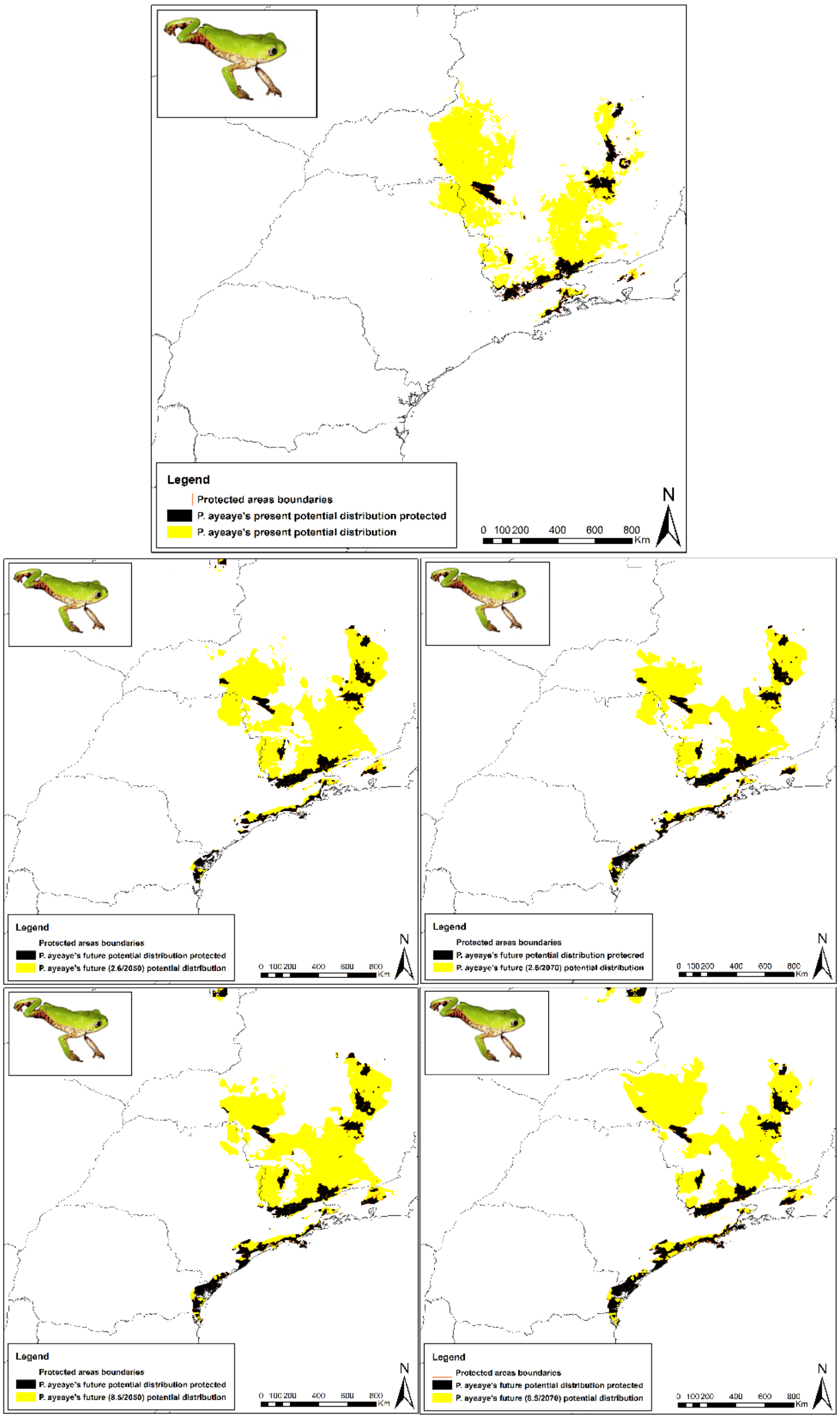


- ***Pithecopus rohdei***

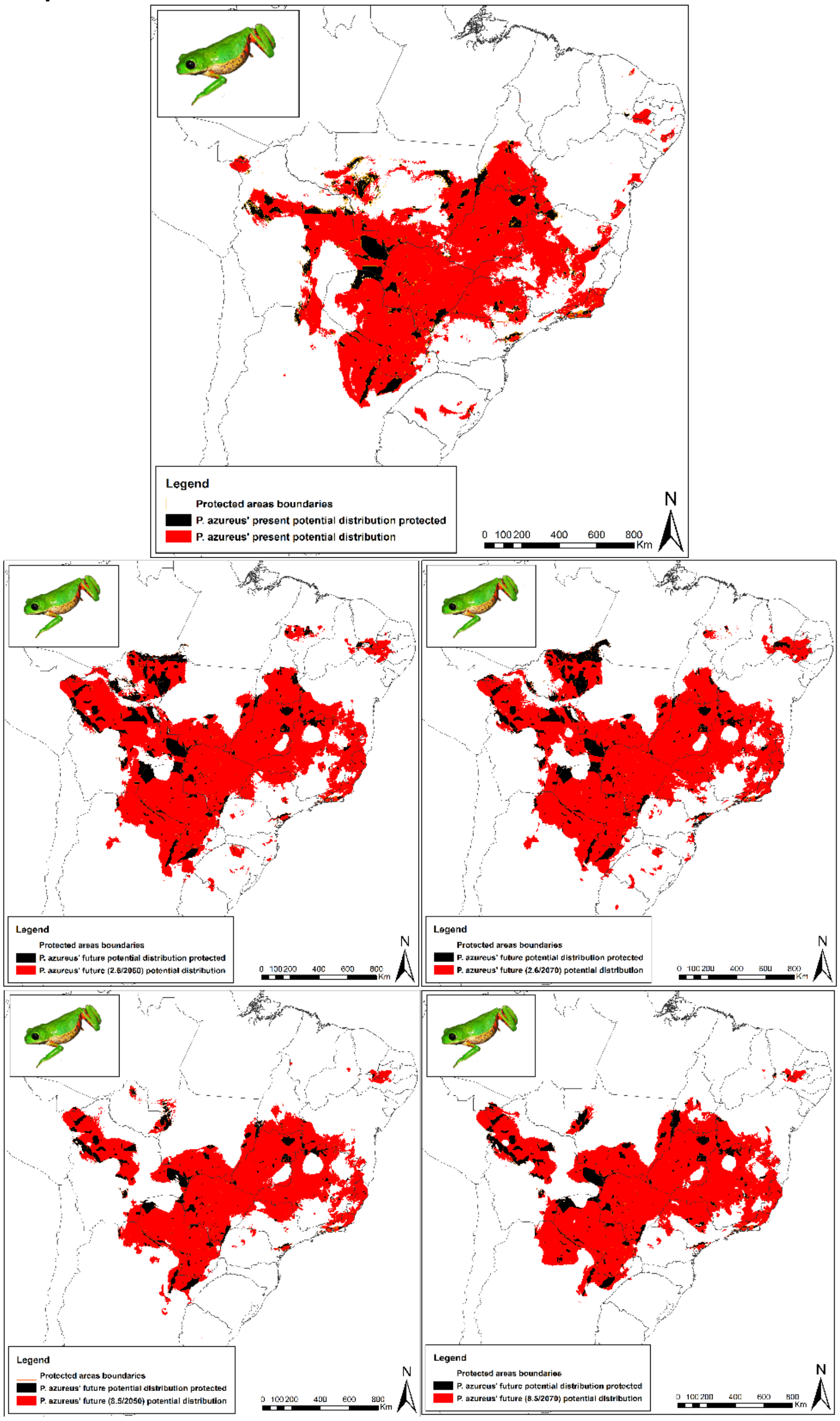


3.4 – What is protected?

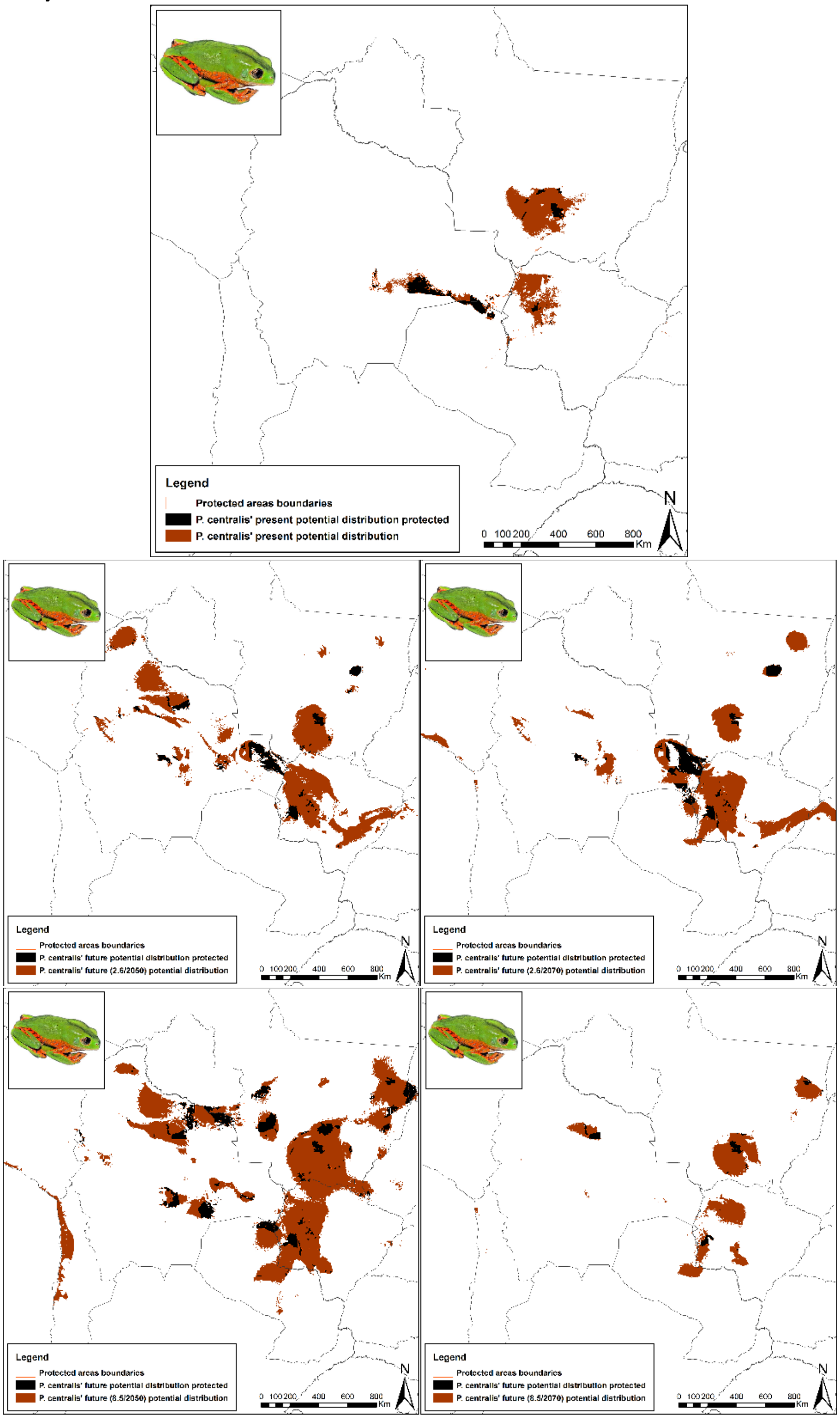
- ***Pithecopus ayeaye***



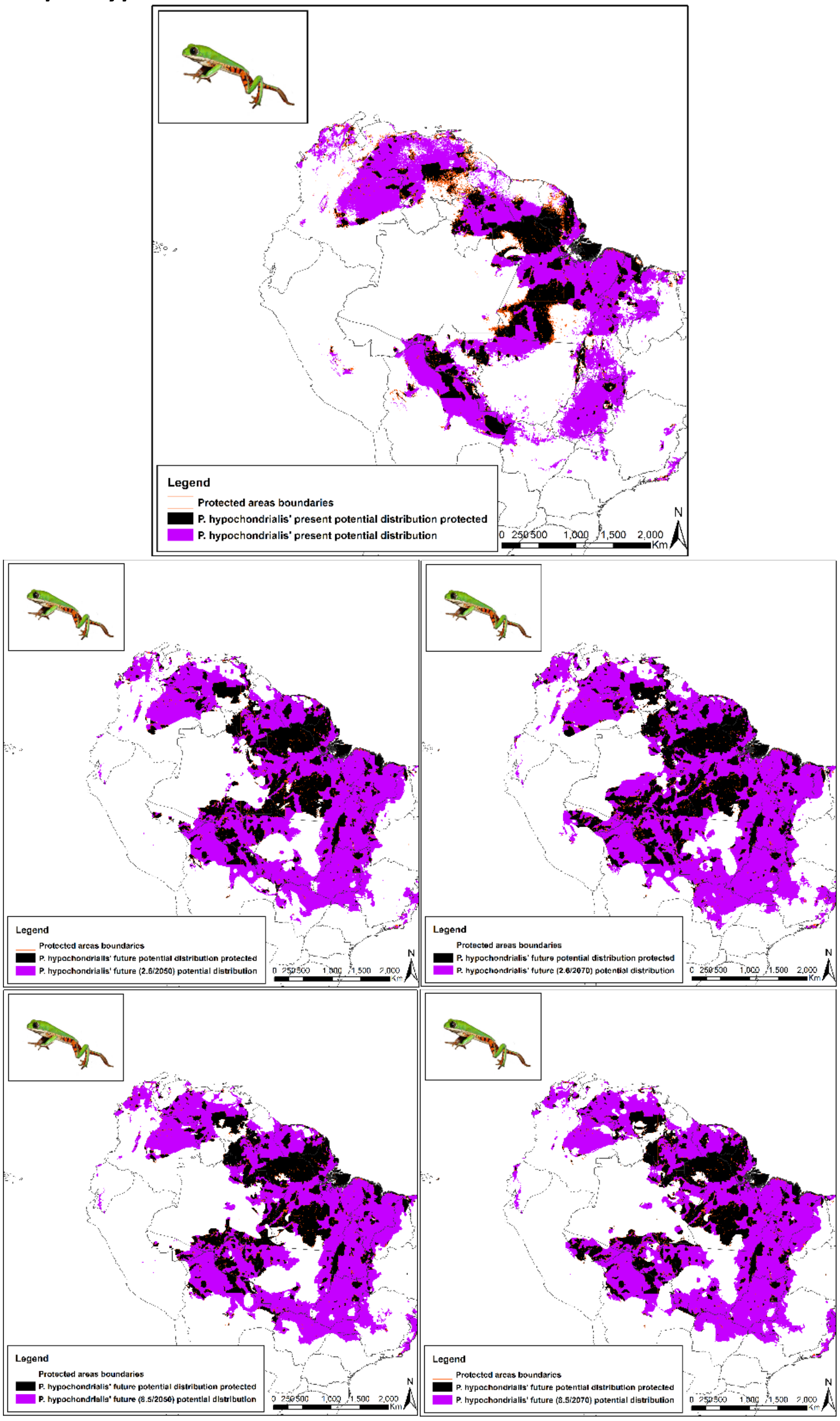
- ***Pithecopus azureus***



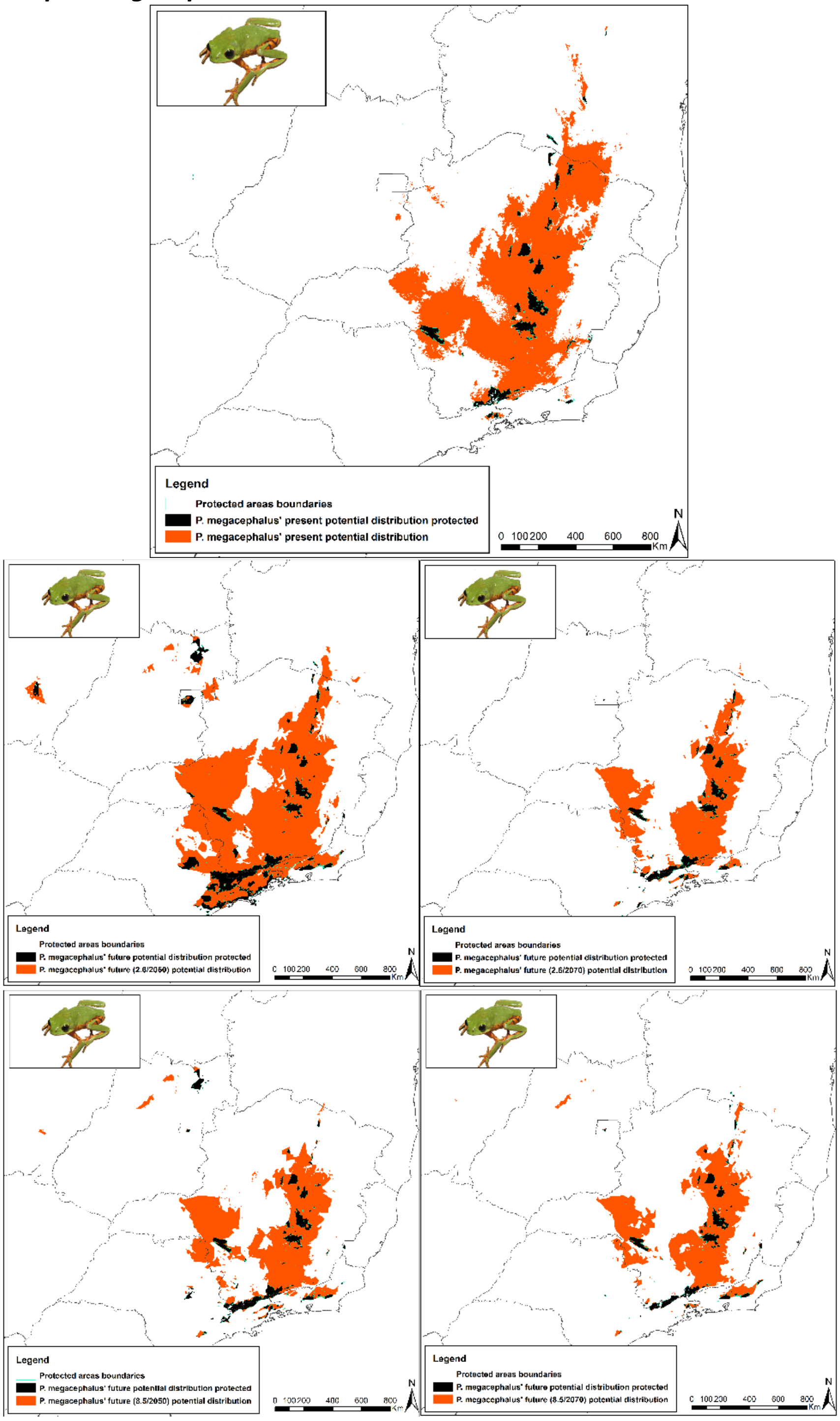
- ***Pithecopus centralis***



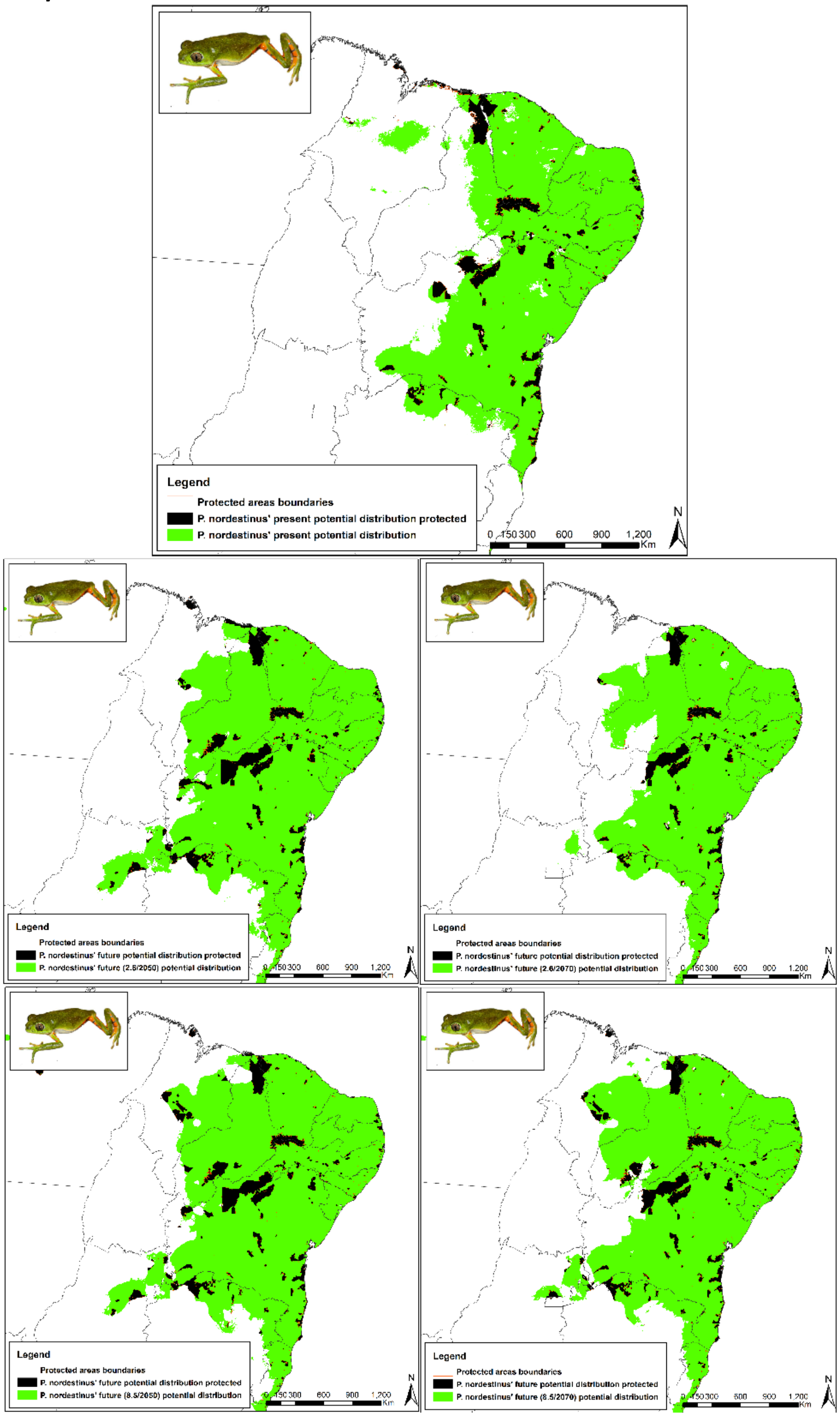
- ***Pithecopus hypochondrialis***



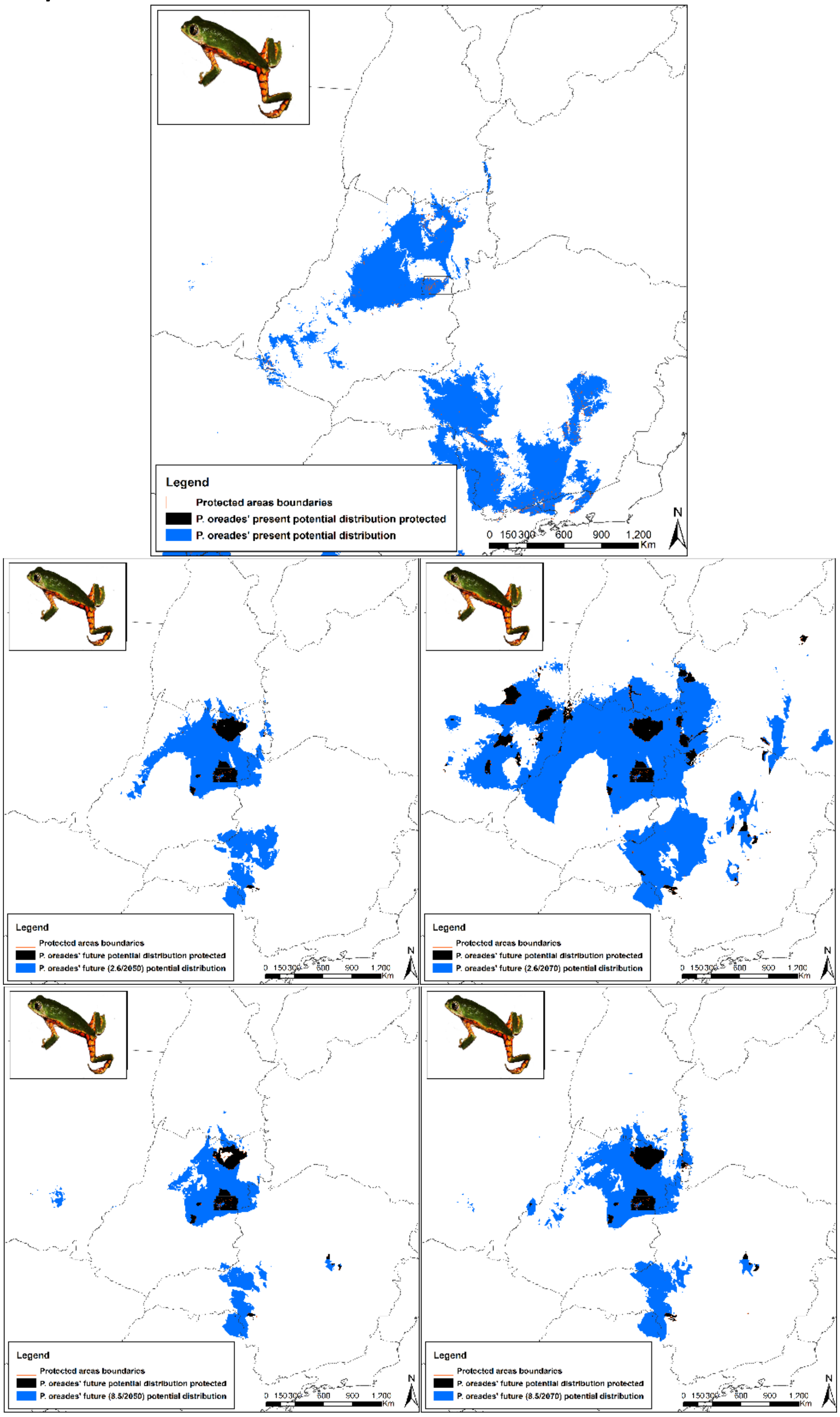
- ***Pithecopus megacephalus***



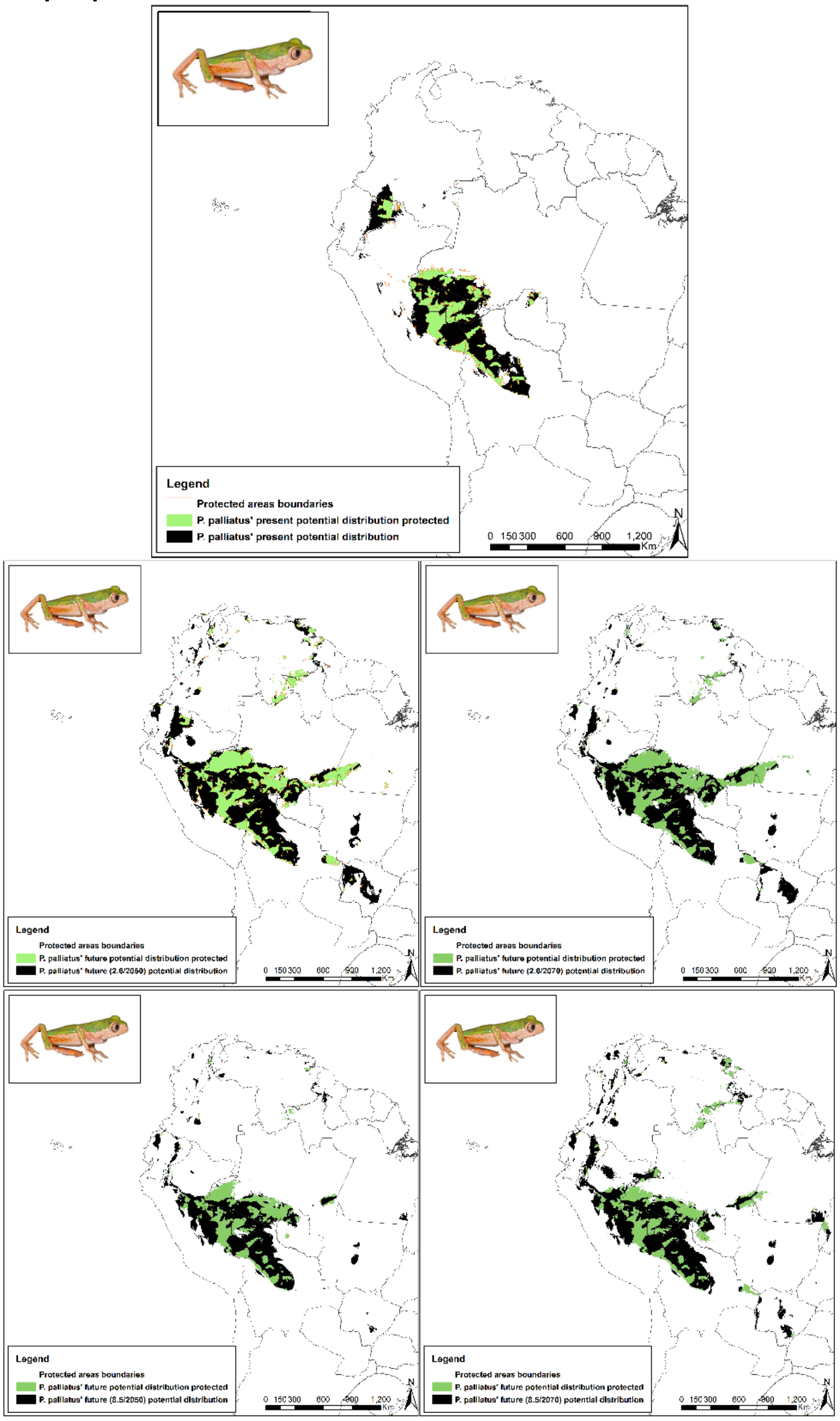
- ***Pithecopus nordestinus***



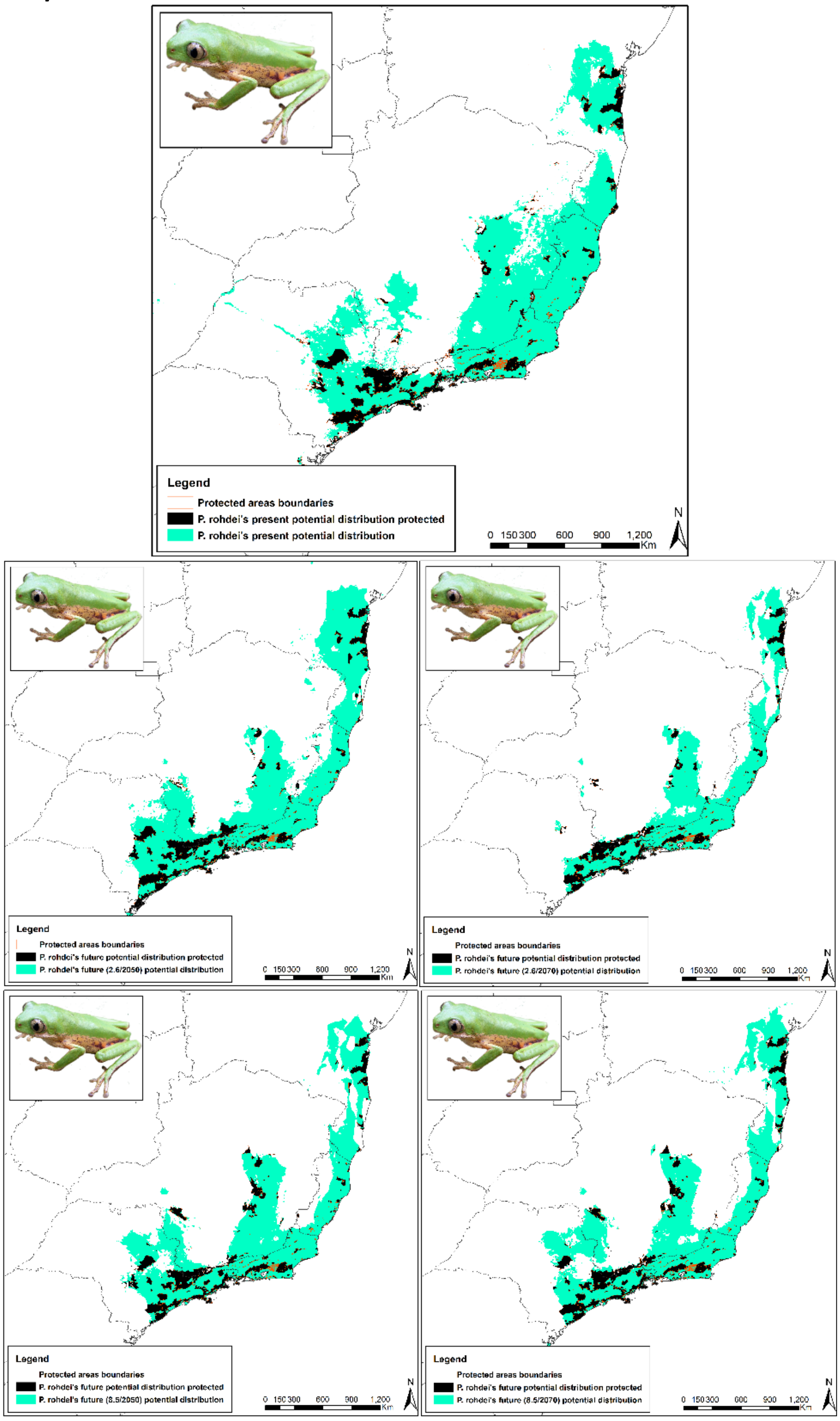
- ***Pithecopus oreades***



- ***Pithecopus palliatus***



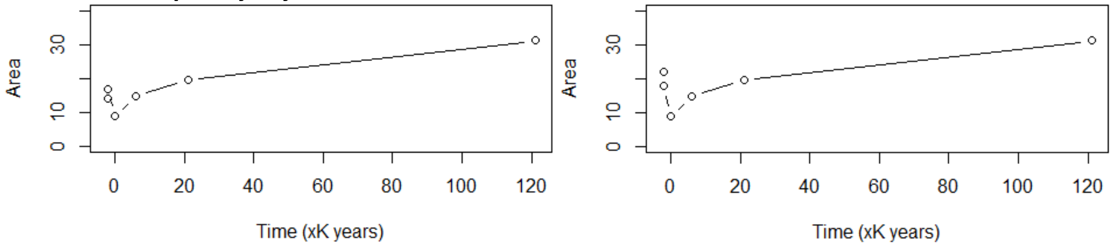
- ***Pithecopus rohdei***



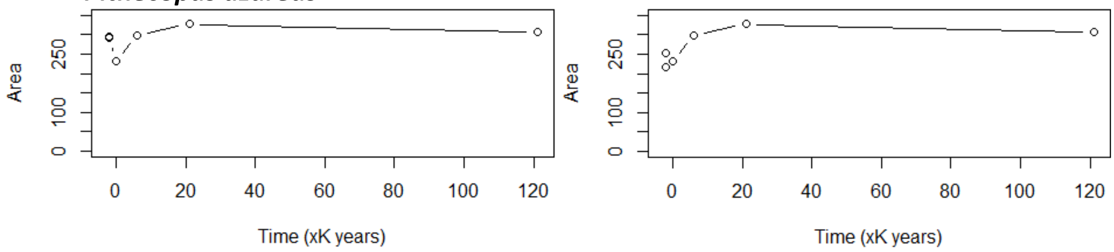
3.4 – Performing descriptive analyzes.

3.4.1 - Variation of the total area predicted as presence in different climatic scenarios.

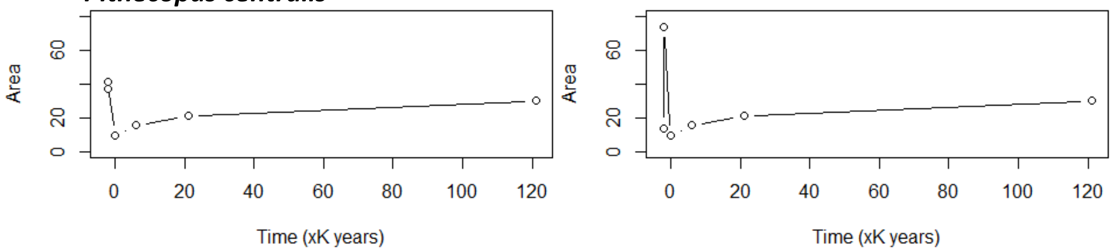
- ***Pithecopus ayeaye***



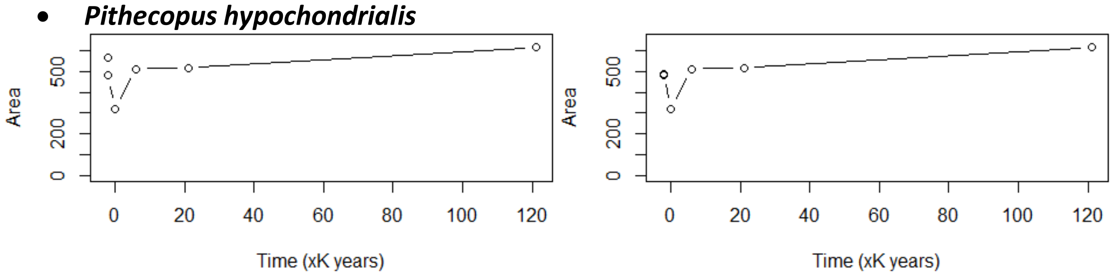
- ***Pìthecopus azureus***



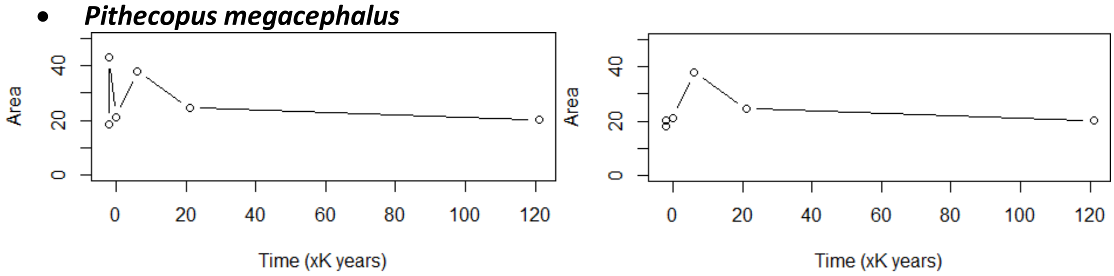
- ***Pithecopus centralis***



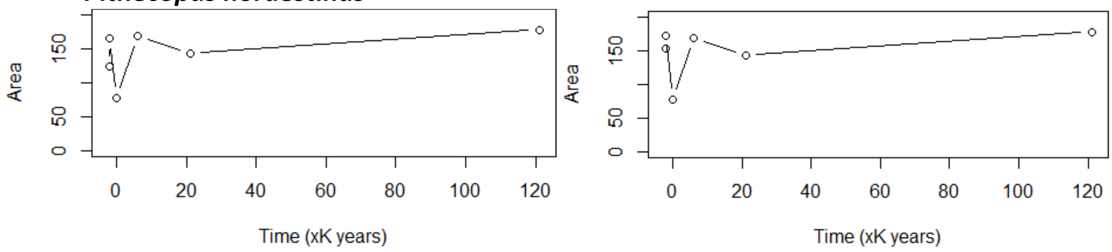
- ***Pithecopus hypochondrialis***



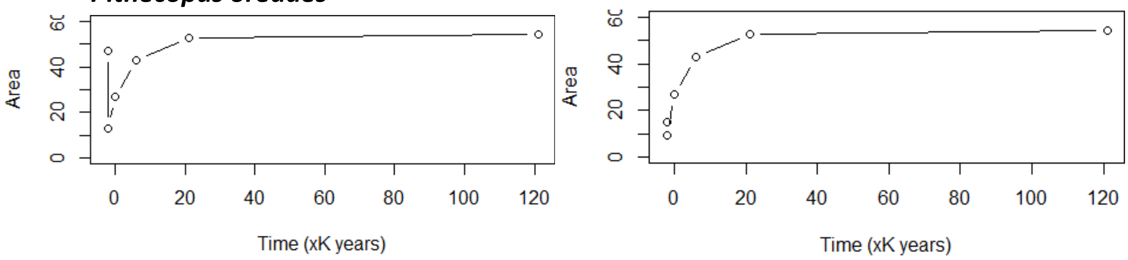
- ***Pithecopus megacephalus***



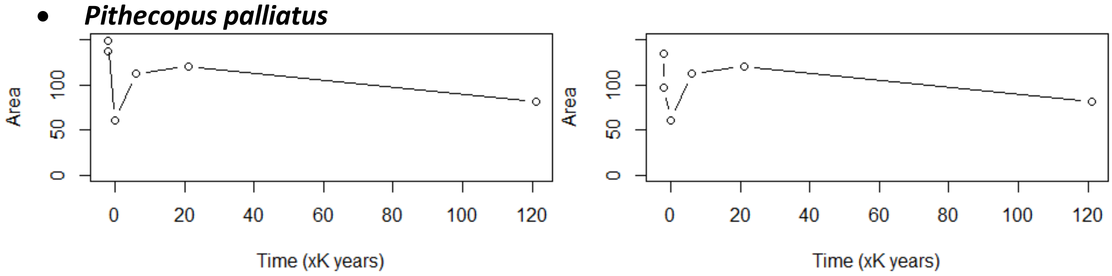
- ***Pithecopus nordestinus***



- ***Pithecopus oreades***



- ***Pithecopus palliatus***



- ***Pithecopus rohdei***

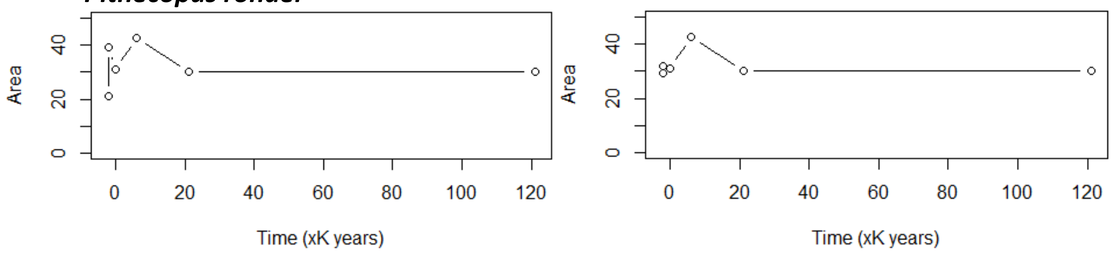


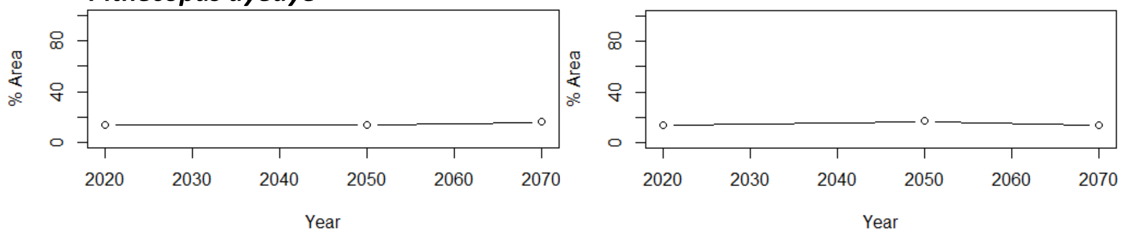
Table 1: Variation of the total area predicted as presence in different climatic scenarios. RCP 2.6% = a very low Representative Concentration Pathway; RCP 8.5% = very high Representative Concentration Pathway (-2.7 = Future – year 2070; -2.5 = Future – year 2050; 0k = present; 6k = Mid-holocene; 21k = Last Glacial Maximum -LGM and, 120k = Last Inter Glacial - LIG).

	Time periods							
	Past			**Present**	**Future**			
					RCP 2.6%		**RCP 8.5%**	
	LIG	**LGM**	**MID**	**PRES**	**2050**	**2070**	**2050**	**2070**
P.ayeaye	31.17648	19.63944	14.81782	8.839091	16.91121	14.18586	17.84789	22.20385
P.azureus	306.1254	327.4412	298.8046	231.3861	293.4575	295.875	215.881	252.7626
P.centralis	30.0239	21.1513	15.4954	9.4648	41.2258	37.3686	74.0379	13.8718
P.hypochondrialis	613.0418	517.4849	511.3387	321.5298	478.788	564.5652	487.8473	478.503
P.megacephalus	20.07483	24.49573	37.93602	21.16332	42.9334	18.60357	20.20273	17.90814

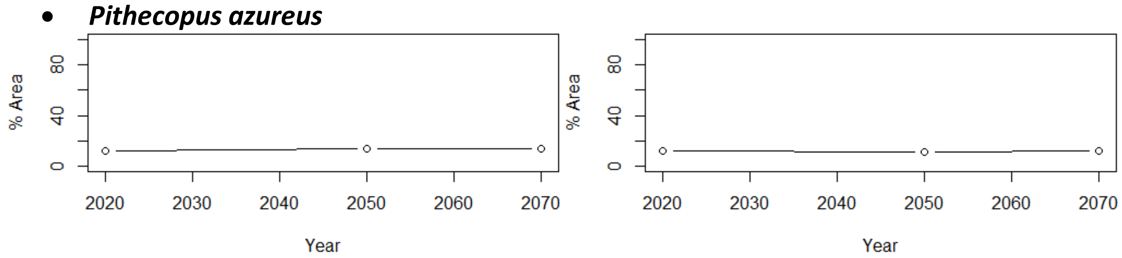
P.nordestinus	177.8651	142.8253	169.4186	77.59136	165.4484	123.3519	172.669	154.0188
P.oreades	54.04355	52.62949	42.73656	26.62932	13.01897	47.04516	9.417463	14.71869
P.palliatus	81.78956	120.2734	112.0221	61.28007	148.1024	137.3938	96.77239	134.4699
P.rohdei	30.23155	30.11768	42.75457	30.9692	39.38249	20.97465	31.63843	29.34136

3.4.2 – Conservation Units efficiency.

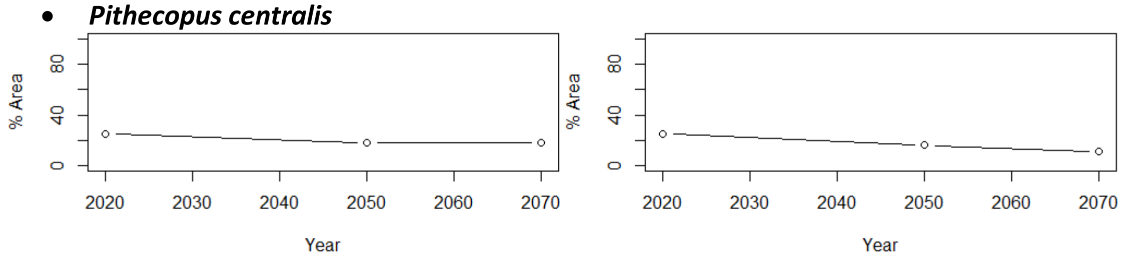
- ***Pithecopus ayeaye***



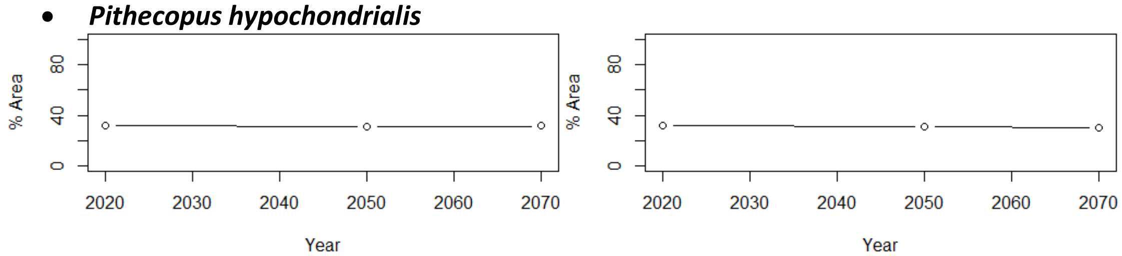
- ***Pithecopus azureus***



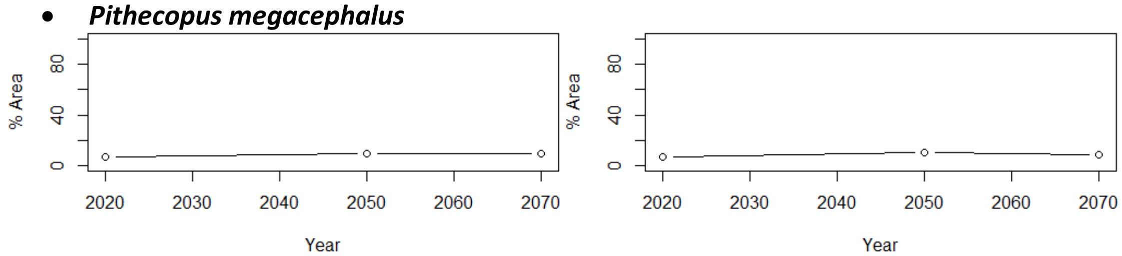
- ***Pithecopus centralis***



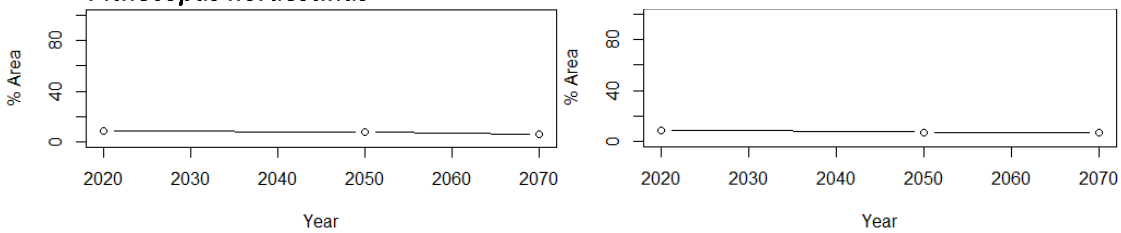
- ***Pithecopus hypochondrialis***



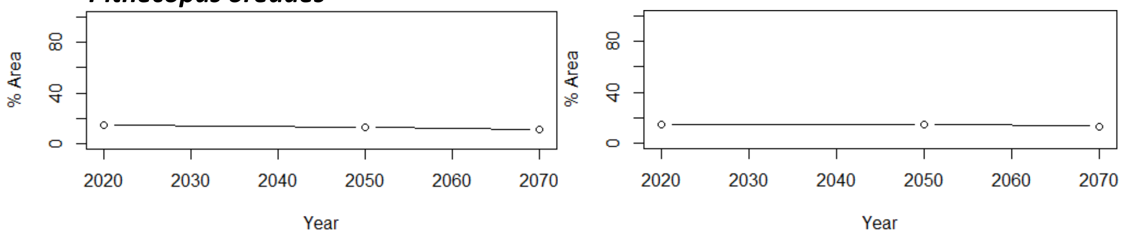
- ***Pithecopus megacephalus***



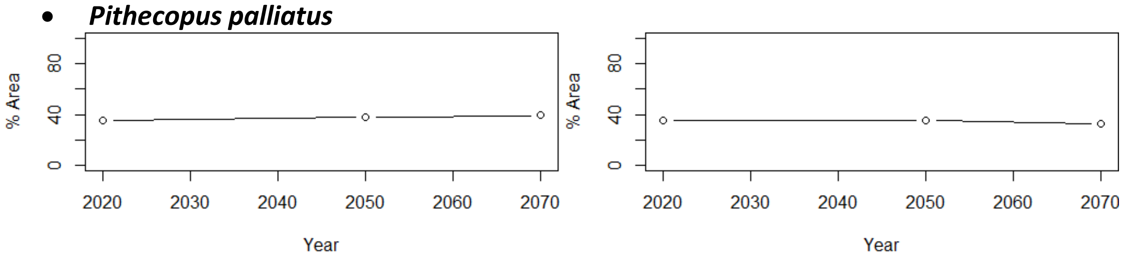
- ***Pithecopus nordestinus***



- ***Pithecopus oreades***



- ***Pithecopus palliatus***



- ***Pithecopus rohdei***

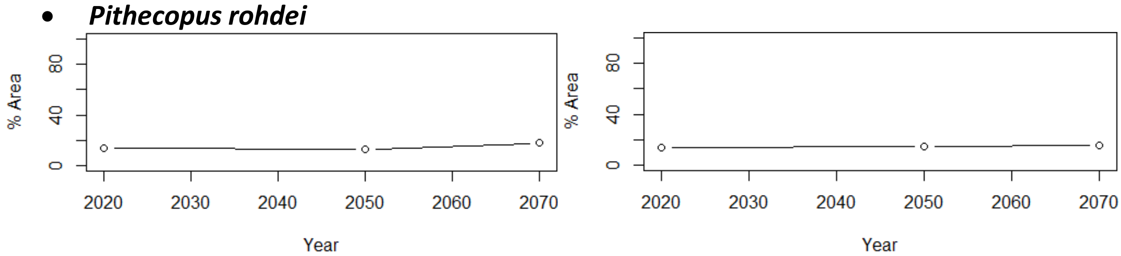


Table 2: Are Conservation Units efficient? Percentage of areas predicted as presence within Conservation Units - UC's. RCP 2.6% = a very low Representative Concentration Pathway; RCP 8.5% = very high Representative Concentration Pathway.

PERCENTAGE OF POTENTIAL PREDICTED AREA WITHIN UC's					
	Present	**Future**			
		RCP 2.6%		**RCP 8.5%**	
	2020	**2050**	**2070**	**2050**	**2070**
P.ayeaye	14.01	13.88	15.90	16.75	13.74
P.azureus	11.65	13.80	13.76	11.09	11.65
P.centralis	24.90	18.00	18.41	16.03	10.83
P.hypochondrialis	31.84	31.16	31.40	30.71	29.81
P.megacephalus	6.83	9.10	9.10	10.25	8.57
P.nordestinus	8.32	7.37	6.30	7.25	6.72

P.oreades	14.52	12.92	10.92	14.96	13.27
P.palliatus	35.21	37.70	39.19	35.47	32.76
P.rohdei	13.55	12.81	17.66	14.52	15.68

4 – Final steps.

As an outcome for our investigation, we will organize all these results in formal documents (i.e., chapters of my doctoral thesis), following the scientific rigidity necessary for publication in renowned journals of high impact in the scientific community, as well as the organization of these in by-products of broad spectrum (e.g., social media); with this we hope to cover a large audience, from researchers to laypeople.

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