Environmental suitability for *Lutzomyia (Nyssomyia) whitmani* (Diptera: Psychodidae: Phlebotominae) and the occurrence of American Cutaneous Leishmaniasis in Brazil

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Leishmaniasis represents an important public health problem in Brazil. The continuous process of urbanization and expansion of human activities in forest areas impacts natural habitats, modifying the ecology of some species of *Leishmania*, as well as its vectors and reservoirs and, consequently, changes the epidemiological pattern and contribute to the expansion of American Cutaneous Leishmaniasis (ACL) in Brazil. In epidemiology of ACL, we highlight *Lutzomyia* (*Nyssomyia*) *whitmani*, the main vector of ACL, transmitting two dermotropic *Leishmania* spp.: *Leishmania* (*Viannia*) *braziliensis* and *Leishmania* (*Viannia*) *shawi*. We used the maximum entropy niche modeling approach (MAXENT) to evaluate the environmental suitability of *L.* (N.) *whitmani* and the transmission of ACL in Brazil, in addition to designing models for a future scenario of climate change. MAXENT was used under the "auto-features" mode and the default settings, with 100-fold repetition (bootstrap). The logistic output was used with higher values in the Habitat Suitability Map, representing more favorable conditions for the occurrence of *L.* (*N.*) *whitmani* and human cases of ACL. Two models were developed: *Lutzomyia whitmani* model (LWM) and American Cutaneous Leishmaniasis model (ACLM). LWM identified that the species "prefers" (more appropriate habitat) regions with moderate Annual Precipitation (AP), between 1,000 - 1,600 mm, intermediate vegetation density (NDVI) values, Mean Temperature of The Coldest Quarter (MTCQ), between 15°C - 21°C, and Annual Mean Temperature (AMT), between 19°C - 24°C. ACLM indicates that ACL is strongly associated with areas of intermediate density vegetation, areas with Annual Precipitation (AP) between 800 and 1200 mm, MTCQ above 16 ° C and AMT below 23°C. The results obtained in this study are discussed in terms of epidemiology and surveillance of ACL in future scenarios in Brazil.

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ABSTRACT

Leishmaniasis represents an important public health problem in Brazil. The continuous process of urbanization and expansion of human activities in forest areas impacts natural habitats, modifying the ecology of some species of *Leishmania*, as well as its vectors and reservoirs and, consequently, changes the epidemiological pattern and contribute to the expansion of American Cutaneous Leishmaniasis (ACL) in Brazil. In epidemiology of ACL, we highlight *Lutzomyia* (*Nyssomyia*) *whitmani*, the main vector of ACL, transmitting two dermotropic *Leishmania* spp.: *Leishmania* (*Viannia*) *braziliensis* and *Leishmania* (*Viannia*) *shawi*. We used the maximum entropy niche modeling approach (MAXENT) to evaluate the environmental suitability of *L.* (*N.*) *whitmani* and the transmission of ACL in Brazil, in addition to designing models for a future scenario of climate change. MAXENT was used under the "auto-features" mode and the default settings, with 100-fold repetition (bootstrap). The logistic output was used with higher values in the Habitat Suitability Map, representing more favorable conditions for the occurrence of *L.* (*N.*) *whitmani* and human cases of ACL. Two models were developed: *Lutzomyia whitmani* model (LWM) and American Cutaneous Leishmaniasis model (ACLM). LWM identified that the species "prefers" (more appropriate habitat) regions with moderate Annual Precipitation (AP), between 1,000 - 1,600 mm, intermediate vegetation density (NDVI) values, Mean Temperature of The Coldest Quarter (MTCQ), between 15°C - 21°C, and Annual Mean Temperature (AMT), between 19°C - 24°C. ACLM indicates that ACL is strongly associated with areas of intermediate density vegetation, areas with Annual Precipitation (AP) between 800 and 1200 mm, MTCQ above 16 ° C and AMT below 23°C. The results obtained in this study are discussed in terms of epidemiology and surveillance of ACL in future scenarios in Brazil.

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INTRODUCTION

The simplification of biological communities, the fragmentation and loss of habitats resulting from human occupation modify the parasite/host interactions, which may lead to the emergence and reemergence of several diseases in animal and human populations (Begon, Harper & Townsend, 1990).

In the last decade, a growing number of studies have investigated the effects of biodiversity on the risk of disease occurrence, mainly due to the interest in identifying and evaluating the importance of biodiversity and the environmental services it provides (Loreau et al., 2001). The influence of diversity on transmission cycles has been described for some diseases (Van Buskirk & Ostfeld, 1995; Norman et al., 1999; Allan, Keesing & Ostfeld, 2003; Allan et al., 2009; Telfer et. al., 2005; Vaz et al., 2007). However, little is known about the ecological mechanisms related to these effects (Keesing, Holt & Ostfeld, 2006). Understanding the structure and functioning of the ecological processes involved in the dynamics of the interactions between parasites, hosts and the environment becomes critical in order to comprehend the relationship between biodiversity and the emergence or reemergence of zoonoses.

Due to the new and complex epidemiological scenarios, Leishmaniasis are considered reemerging diseases (WHO, 2010) and important public health problems in Brazil. American Cutaneous Leishmaniasis (ACL) represents an example of zoonosis related to land use and biodiversity management, both by the severity of the disease and by the direct relationship of elements and the environmental context (landscape) in its transmission cycle (Fonseca et al., 2014).

The circulation of phlebotomine vectors (sandfly) in environments outside the geographical limits of natural foci is increasing, and leads to modifications in the classic epidemiological patterns (wild, occupational/leisure, and rural/periurban. For more detail, see (Brasil, 2013). Such modifications are related to changes in the determinant factors for the exposure of man to transmission, demographic expansion and the process of urbanization on the limits of natural foci, as well as the occurrence of forest remnants adjacent to urban areas (Lainson & Rangel, 2005; WHO, 2010; Brazil, 2013).

In this context, we highlight *Lutzomyia* (*Nyssomyia*) *whitmani*, sandfly species registered in 25, of the 27 Brazilian federative units (Costa et al., 2007) and incriminate it as transmitter of two dermotropic leishmaniasis: *Leishmania* (*Viannia*) *shawi*, in the Amazon, and *Leishmania* (*Viannia*) *braziliensis*, in the North, Northeast, Midwest, Southeast and South Regions (Lainson & Shaw, 2005; Rangel & Lainson, 2009). The species presents different behavior in different regions, has a wide geographical distribution, and is adapted to several climates and types of vegetation cover (Costa et al., 2007; Rangel & Lainson, 2003; Rangel & Lainson, 2009). This ecological plasticity reflects the occurrence of this species in all epidemiological patterns described for ACL (Brasil, 2013). Throughout Brazilian territory, according to qualitative changes related to antrophilia and domesticity, Lainson (1988) suggested that *L.* (*N.*) *whitmani* represented a complex of cryptic species.

The characterization of factors influencing the spatial distribution of the species, in general, has been an efficient tool for a better understanding of ecological processes. The Ecological Niche Models (ENM) has been widely used as a tool to describe conditioning factors and to identify patterns related to environmental suitability for species occurrence (Guisan & Zimmerman, 2000; Franklin, 2010; Peterson et al., 2011). In recent years, many techniques for modeling niches and species distributions have been developed and applied extensively in biogeography, ecology and conservation studies (Guisan & Zimmerman, 2000; Guisan & Thuiller, 2005; Elith & Leathwick, 2009). The maximum entropy model (Maxent), (Elith et al., 2006) is consistently competitive with the highest performing methods, and is one of the most common approaches used to determine geographic distribution and ecological features of species (Elith et. al., 2011; Renner & Warton, 2013; Václavík & Meentemeyer, 2009; Braunisch & Suchant, 2010; Rebelo & Jones, 2010; Rodríguez-Soto et. al., 2011).

Peterson and Shaw (2003) modeled three sandfly vector species (*L.* (*N.*) *whitmani*, *L.* (*Nyssomyia*) *intermedia* and *L. migonei*) for South America, and identified an increase in areas of climate suitability for the year 2050. According to the models, *L.* (*N.*) *whitmani* presented the greatest areas of dispersion. The purpose of the present; study was to evaluate the environmental suitability and project future scenarios (via ENM), for *L.* (*N.*) *whitmani* and for the ACL in Brazil, in face of global climate change.

MATERIALS AND METHODS

Occurrence data

For data related to the occurrence of the disease, we used municipalities with records of endemic areas for ACL (N = 1882, of which 1506 were used for modeling and 376 for additional accuracy test). For *L. (N.) whitmani* occurrence, the municipalities with confirmed record of vector (N = 992, of which 794 were used for modeling and 198 for additional accuracy test) were considered in *L. (N.) whitmani* model.

This set of occurrence data was extracted from previously published data (online databases, PubMed, http://www.ncbi.nlm.nih.gov/pubmed; ISI Web of Knowledge, http://apps.webofknowledge.com and SCOPUS, Http://www.scopus.com, CAPES). We also collected unpublished records from the Health Departments of Brazil and from major Brazilian sandfly collections (Centro de Pesquisas Rene Rachou - FIOCRUZ, Instituto Evandro Chagas - IEC and Faculdade de Saude Publica—USP).

Environmental descriptors

Ten environmental variables (0.04° of spatial resolution, ~ 5 km) were used, eight of which were WorldClim (Hijmans et al., 2005) climatic variables, as well as data on altitude and vegetation indices, all displayed in Table 1. The adopted variables are commonly used in species distribution predictions, and consist of easily usable ecological information.

For the projection to the environmental conditions of the future (2050), we used two Representative Concentration Pathways (RCPs) of HadGEM2-ESGeneral Circulation Model: RCP 4.5 and RCP 8.5 greenhouse gas concentration trajectories adopted by the IPCC for its fifth Assessment Report (AR5) in 2014 (IPCC, 2013). These were selected to represent contrasting scenarios in projections for climate change. RCP 4.5 represents a relatively optimistic scenario and assumes that the radiative forcing of greenhouse gas stabilizes shortly after 2100, and RCP 8.5, more pessimistic, radiative forcing keeps rising after 2100.

Ecological Niche Models

We used the maximum entropy niche modelling approach, as implemented in the MAXENT software (version 3.3.3k), to evaluate the environmental suitability for *L. (N.) whitmani* and occurrence of ACL in Brazil, as well as to model projections for future climate change scenarios. The method considers the requirement of the species based on presence and on the set of environmental variables (Phillips, Anderson & Schapire, 2006), providing environmental variable response curves which indicate how each variable affects the predicted distribution (Phillips & Dudík, 2008). MAXENT has been shown to be robust for ENM construction from presence-only data (Elith et. al., 2006), and to describe of the ecological and spatial relationships between species and environmental conditions.

MAXENT was applied under the 'auto-features' mode and the default settings, with 100-fold replicates generated by bootstrap (Phillips & Dudík, 2008). The logistic output was used (habitat suitability on a scale of 0–1), with higher values in the Habitat Suitability Map (HSM) representing more favorable conditions for the occurrence of the *L. (N.) whitmani* or ACL. Two models were developed: i) the *Lutzomyia whitmani* model (LWM), and ii) American Cutaneous Leishmaniasis model (ACLM). Both models were developed using 10 environmental variables and 80% of occurrence data for training and 20% for test.

In order to infer the effect of climate change on the distribution of *L. (N.) whitmani* and ACL, each model was projected using both scenarios, RCP 4.5 and RCP8.5. For these projections, the NDVI environmental variable was removed.

We assessed the accuracy of each model using the AUC (area under the receiver operating characteristic [ROC] curve). Additionally, we used an independent set of 127 and 376 actual occurrence records, for *L. (N.) whitmani* and ACL human cases, respectively (randomly selected from total points and not used in the generation of models), to evaluate the predictive capacity of the models. The predicted suitability of the models was extracted for each test point, and the average suitability was used to evaluate model accuracy.

For *L. (N.) whitmani* and ACL potential distribution binary maps (suitable/unsuitable) were applied the Minimum Training Presence (MTP) as a threshold value for models, because it is the most conservative threshold, identifying the minimum predicted area possible while still maintaining a zero omission rate for both training and test data.

For comparative purposes, the images resulting from each model (with continuous values from 0 to 1) were reclassified into five environmental suitability zones: (1) Unsuitable Zone (UNSZ; value pixel suitability < Minimum Training Presence, MTP), (2) Low Suitability Zone (LSZ, value pixel suitability between MTP value and 0.25), (3) Intermediate Suitability Zone (ISZ, value pixel suitability between 0.25 and 0.50), (4) High Suitability Zone (HSZ, value pixel suitability 0.50 and 0.75), and (5) a Very High Suitability Zone (VHSZ, value pixel suitability >0.75).

Model Comparison

The generated models ACLM and LWM were compared using Fuzzy for continuous maps, and Kappa index for categorical maps (suitable/unsuitable) using Map Comparison Kit v.3.2, software developed by the Netherlands Environmental Assessment Agency (Visser & Nijs, 2006; Hagen, 2002; Hagen-Zanker, Straatman & Uljee, 2005). Both indices express the pixel similarity for a value between 0 (fully distinct) and 1 (fully identical).

Additionally we used Olson et al.'s (2001) delineation of the terrestrial “Ecoregions of the World" and the Brazilian biomes (IBGE) as base map to better demonstrate the comparison between generated.

RESULTS

With an average AUC of 0.77 (SD = 0.004; 100-fold replicates), the ACLM achieved a satisfactory model fit and the modeled distribution performed better than random. The predictive capacity of ACLM, evaluated by the average suitability test of 0.53 (SD = 0.12) in each test point, indicates that the model achieved high accuracy. This average value corresponds to the High Suitability Zone for ACL. Based on the Minimum Training Presence (MTP = 0.07) cutoff criteria (MTP = 0.07), the ACLM identified many of the regions of Brazil appropriate for the occurrence of ACLM (Figure1), covering 82.3% of the Brazilian territory. The LWM model showed similar performance, mean AUC of 0.82 (SD = 0.006; 100-fold replicates) and average suitability test of 0.54 (SD = 0.15), indicating satisfactory predictive capacity of both models (Figure 1), covering 83.4% of the Brazilian territory.

The vegetation density index (NDVI) was the variable with the highest gain in the model, when it was omitted or used alone, the significance of the ACLM model decreased. The response curves for EV of this model indicate that ACL are strongly associated with intermediate density vegetation areas, zones with Annual Precipitation (AP) between 800 to 1200 mm, Mean Temperature of Coldest Quarter (MTCQ) above 16°C, and Annual Mean Temperature (AMT) lower than 23°C (suitability of occurrence > 0.5) (Figure 2A; 3A).

Lutzomyia (Nyssomyia) whitmani was identified by the LWM model as a species that occurs "prefers" (more suitable habitat) in regions with relative moderate rainfall (AP between 1000 - 1600 mm), intermediate density vegetation values (NDVI), and regions with MTCQ between 15° - 22°C and AMT between 19° - 24°C (Figure 2B; 3A). These characteristics are in accordance with previous analysis discussing the distribution of this sandfly vector in Brazilian biomes, occurring in high frequency in Southern Brazil, Amazonian region, Caatinga and Pantanal biomes showing low suitability and unsuitable areas (based on MTP = 0.06) in the LWM.

Figure 1 shows the future predicted distributions for ACL and *L. (N.) whitmani* in 2050, under both the RCP 4.5 and RCP 8.5 (HadGEM2-ES model) for future climate scenarios. For ACL model these two projections differ moderately from current scenario (Fuzzy of 0.58 and 0.59, for RCP 4.5 and RCP 8.5 respectively) and are very similar to each other (Fuzzy of 0.75). Similar results were found in the projections for *L. (N.) whitmani* (Figure 1), but with greater similarity (Fuzzy of 0.74 and 0.64, for current model versus RCP 4.5 and RCP 8.5 respectively, and Fuzzy of 0.77 between future climate scenarios).

Comparisons between the models for ACL and *L. (N.) whitmani* indicate high similarity. Fuzzy of 0.77, between current models, and 0.77 and 0.78, for RCP 4.5 and RCP 8.5 scenarios, respectively.

All the projections presented gain in area in the coverage of the Brazilian territory. *L. (N.) whitmani* increases by 5% in the RCP 4.5 scenario and in 7.6% in the RCP 8.5 scenario. For ACL the area gain values were relatively higher (12.3% and 15.5% area gain, RCP 4.5 and RCP 8.5 respectively).

Suitable areas (above MTP cutoff values) for *L. (N.) whitmani* are more extensive than those suitable for ACL. Suitability areas for *L. (N.) whitmani* covers 7,113,644.7 km² of Brazilian territory, 1.2% more than the suitability for ACL (7,025,688.6 km²). In future projections, this behavior is repeated, but with higher gain values in the suitable area for this vector (8.8% and 9.1%, RCP 4.5 and RCP 8.5 respectively).

Figure 4 shows the Most Dissimilar variables (MoD) between current and future climate scenarios. The MoD for a point *P* is the variable with respect to which *P* has the smallest value of similarity - i.e., the variable driving the dissimilarity result (Elith et al., 2010). For ACL and *L. (N.) whitmani* the Mean Temperature of Warmest Quarter (MTWAQ), Mean Temperature of Coldest Quarter (MTCQ) and Annual Mean Temperature (AMT) were the drivers of current/future dissimilarity.

DISCUSSION

Lutzomyia (Nyssomyia) whitmani has the ability to "adapt" to environmental changes, new ecological niches, tolerating and overcoming the effects of changes that constantly occur in natural environments (Peterson & Shaw, 2003; Rebelo et. al., 2009). According to Peterson & Shaw (2003), *L. (N.) whitmani*, *L. (N.) intermedia* and *L. migonei*, phlebotomines vectors of ACL widely distributed in South America, in the year 2050 will have their climatic suitability areas increased. These species are expanding to different areas of the continent, and Peterson & Shaw, (2003) identified the southern direction as the most evident for *L. (N.) whitmani*. Our results corroborate this study. However, when using data from the most recent occurrence of *L. (N.) whitmani*, we show that it is predicted to expand even in the current model.

Therefore, the future projections of the LWM model indicate a larger area of expansion of climatic suitability for *L. (N.) whitmani* for the northern region of Brazil, and reinforces the trend of expansion towards the South, as described by Peterson & Shaw (2003). Other vectors of ACL e present projections of future displacements towards higher latitudes, as observed in sandflies from Central and North America (González et al., 2010; Moo-Llanes et al., 2013). *Phlebotomus ariasi* showed increased abundance at higher latitudes in Central Spain. According to the authors, the species would be migrating to these areas in order to compensate for the increase in temperatures in the region (Gálvez et al., 2010). Carvalho et al., (2015) describes an expansion of *Lutzomyia (Nyssomyia) flaviscutellata* to the south and southeast of Brazil in the face of future climatic scenarios. Therefore, one can infer that the area of overlap between these vectors (*L. (Nyssomyia) flaviscutellata* and *L. (N.) whitmani*) will be larger and more evident in the future. Similarly, greater overlap between *L. (N.) whitmani* and *L. neivai* is expected for the southern region, compared to future climate projections.

The results point to the predicted expansion of *L. (N.) whitmani* in the northern region, especially the State of Amazonas: although future projections show that the Amazon region will become drier, as a consequence of the increase in intensity and duration of the dry season (Joetzjer et al., 2013), *L. (N.) whitmani* remains present in the region and will have a more extensive climatic suitability area in the future. Considering the extensive latitudinal range of Brazil, regional climates play an important role in the definition of species distribution. According to Carvalho, Rangel &Vale (2016), most projections of climate change endorse that vectors of diseases will find good climatic conditions for their geographic expansion in the higher latitudes during the coming decades.

In relation to the epidemiology of ACL in Brazil, the disease expansion process is related to environmental changes with new human cases being registered in areas of recent deforestation, mining, hydroelectric plant construction and population settlements (Brazil, 2013; Rangel & Lainson, 2009). These changes in the transmission pattern favor the dispersion of wild animals and sandflies mainly to the peridomestic environment, where new transmission cycles can be established close to houses (Brazil, 2013). In this case, *L. (N.) whitmani* and *L. (N.) flaviscutellata* would be particularly good examples of species, in different epidemiological situations (Rangel et al., 2014). This relationship is identified in the ACLM model by the strong relation of the most suitable areas for ACL with areas of intermediate vegetation cover density. Therefore, the most conserved Amazonian areas are identified as unsuitable.

Future projections for ACL indicate an expansion to northwestern Brazil. This is more evident in the RCP 8.5 scenario, which is more pessimistic in relation to policies to control the emission of greenhouse gases, adding 15.5% to the total area of occurrence of the disease. The lack of future scenarios of the change in density and/or vegetation cover, in the way of those that exist for climatic data, made it impossible to quantify the role of changes in forest cover in future forecasts. However, the known and progressive environmental degradation, associated with future climate predictions that indicate that the Amazon region will tend to become more suitable climatically for both ACL and *L. (N.) whitmani*, design a scenario of higher risk of cases of disease.

The larger distribution predicted in the models for *L. (N.) whitmani* in regard to ACL epidemiology, is possibly related to the sole presence of the vector not being deterministic for the disease. Other factors influence pathogen transmission as well as the development of the disease. However, the little difference between the areas identified as adequate for *L. (N.) whitmani* and ACL, associated with the high similarities between the models reinforce the geographical importance of this vector in the transmission of ACL.

CONCLUSION

Regardless of whether it is a complex of cryptic species or not (Lainson, 1988), it is a fact *that L. (N.) whitmani* has a wide geographic distribution, occurs in all five Brazilian regions, and is an important ACL vector in Brazil. In this context, and in view of the geographic expansion projected for the future, the models reinforce the importance of *L. (N.) whitmani* spatialization in the transmission of ACL in Brazil, and confirm that this ACL vector is well established in the Brazilian territory and will most likely maintain this behavior in the expected climate change.

Although climate change scenarios show that Amazon region will become gradually drier (Joetzjer et al., 2013), the presented results indicate that *L. (N.) whitmani* will remain present in the region and should expand its area of climate suitability in the future.

The models were able to identify that continuous process of environmental degradation favors the establishment of *L. (N.) whitmani* and the occurrence of ACL. Future projections of ACL models indicate the ongoing process of disease expansion in the face of the predicted climatic changes and reinforce the broad geographical expanse of the disease. In this view and associated with the new epidemiological patterns resulting from the drastic environmental changes (coupled with the presence of highly adapted vectors, reservoirs, and parasites) the epidemiological scenario for ACL indicates a continuous increasing of human cases.

Several evidences have suggested that epidemiology of vector-borne diseases are dependent on global climate changes (Gálvez et al., 2010; Gálvez et al., 2011; González et al., 2010). Policies for monitoring / controlling neglected diseases, such as leishmaniasis, should be aligned with agendas committed to assessing climate, besides environmental changes (WHO, 2011)

Considering that changes in the climate can impact the ecoepidemiology of leishmaniasis (WHO, 2010), the results discussed here should be assessed in vector surveillance actions, contributing to the promotion of health in risk areas for ACL associated to *L. (N.) whitmani* , projected for future scenarios in Brazil.

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Table 1(on next page)

Environmental Variables (EV)

Environmental Variables (EV) used to model the potential distribution of *Lutzomyia (N.) whitmani* and American Cutaneous Leishmaniasis in Brazil. All variables were resampled from original resolution to 0.04° (~5km), using the average value of all involved pixels, where the source pixels are covered by the target pixel.

1

Environmental Variable (EV)	**Acronym**	**WorldClim Acronym**	**Source**
Annual Mean Temperature	AMT	BIO1	WorldClim (Hijmans et al.,2005)
Mean Temperature of Wettest Quarter	MTWEQ	BIO8	
Mean Temperature of Driest Quarter	MTDQ	BIO9	
Mean Temperature of Warmest Quarter	MTWAQ	BIO10	
Mean Temperature of Coldest Quarter	MTCQ	BIO11	
Annual Precipitation	AP	BIO12	
Precipitation of Wettest Quarter	PWQ	BIO16	
Precipitation of Driest Quarter	PDQ	BIO17	
Altitude - Digital Elevation Model	ALT	--	Shuttle Radar Topography Mission (http://www2.jpl.nasa.gov/srtm/)
MODIS Normalized Difference Vegetation Index (NDVI)-32 day composites-Oct/15 - Nov/15/2004. Date of the composite represents well the contrast between forest and open formations.	NDVI	--	Global Land Cover Facility (GLCF) (http://www.landcover.org/data/modis/)

2

Figure 1

American Cutaneous Leishmaniasis (ACL) and *Lutzomyia (N.) whitmani* (LW) Models

Environmental suitability for American Cutaneous Leishmaniasis (ACL) and *Lutzomyia (N.) whitmani* (LW) in Brazil. Current conditions and future climate projections

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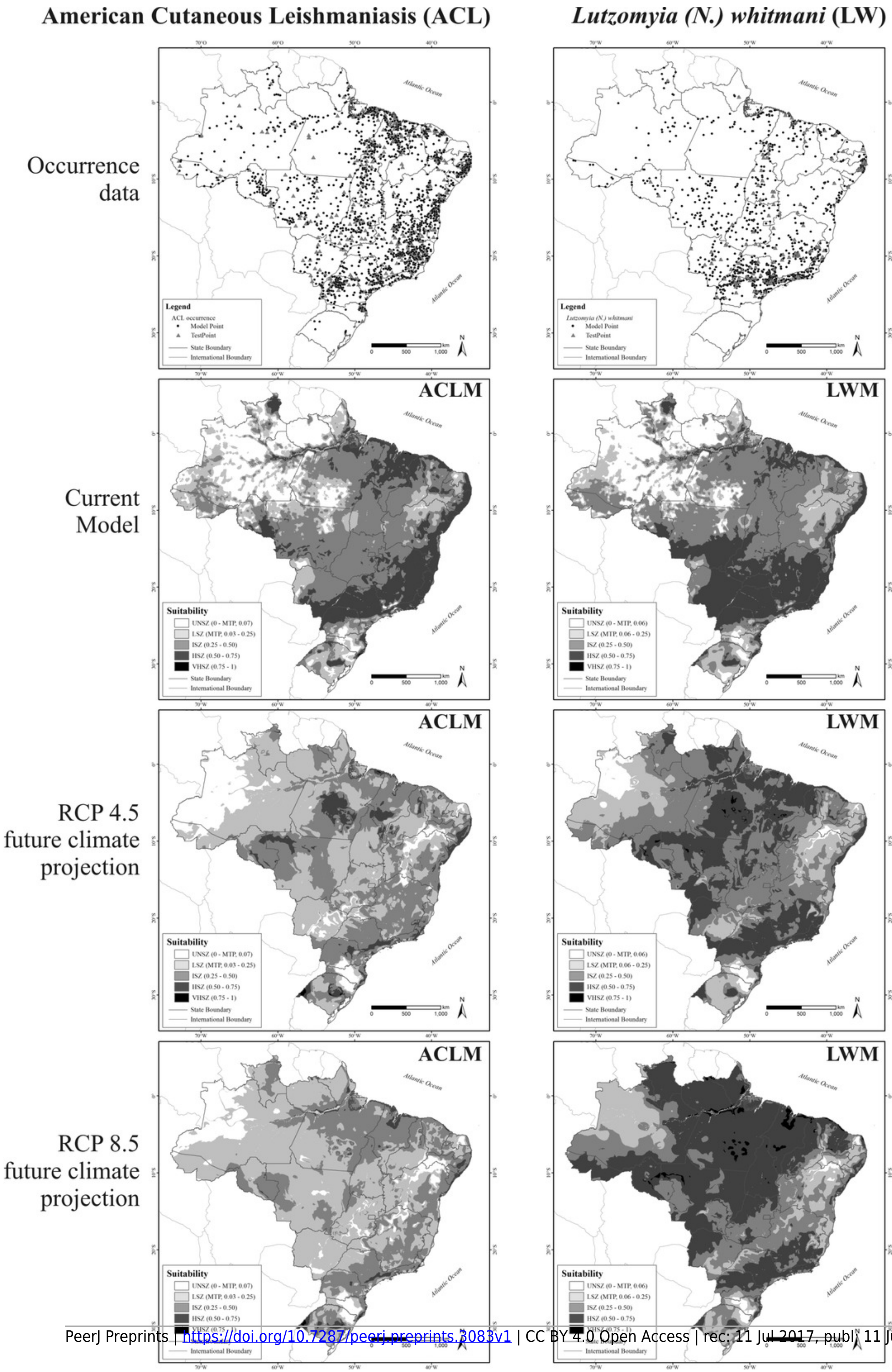

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Figure 2

Response-curves of the variables in the American Cutaneous Leishmaniasis Model (ACLM), and *Lutzomyia (N.) whitmani* Model (LWM)

Response-curves of the variables in the (A) American Cutaneous Leishmaniasis Model (ACLM), and (B) *Lutzomyia (N.) whitmani* Model (LWM). Normalized Difference Vegetation Index (NDVI), Annual Precipitation (AP – BIO12), Mean Temperature of Coldest Quarter (MTCQ – BIO11), Annual Mean Temperature (AMT – BIO1). These curves show how each environmental variable affects the MAXENT prediction when all environmental variables are used to build the model

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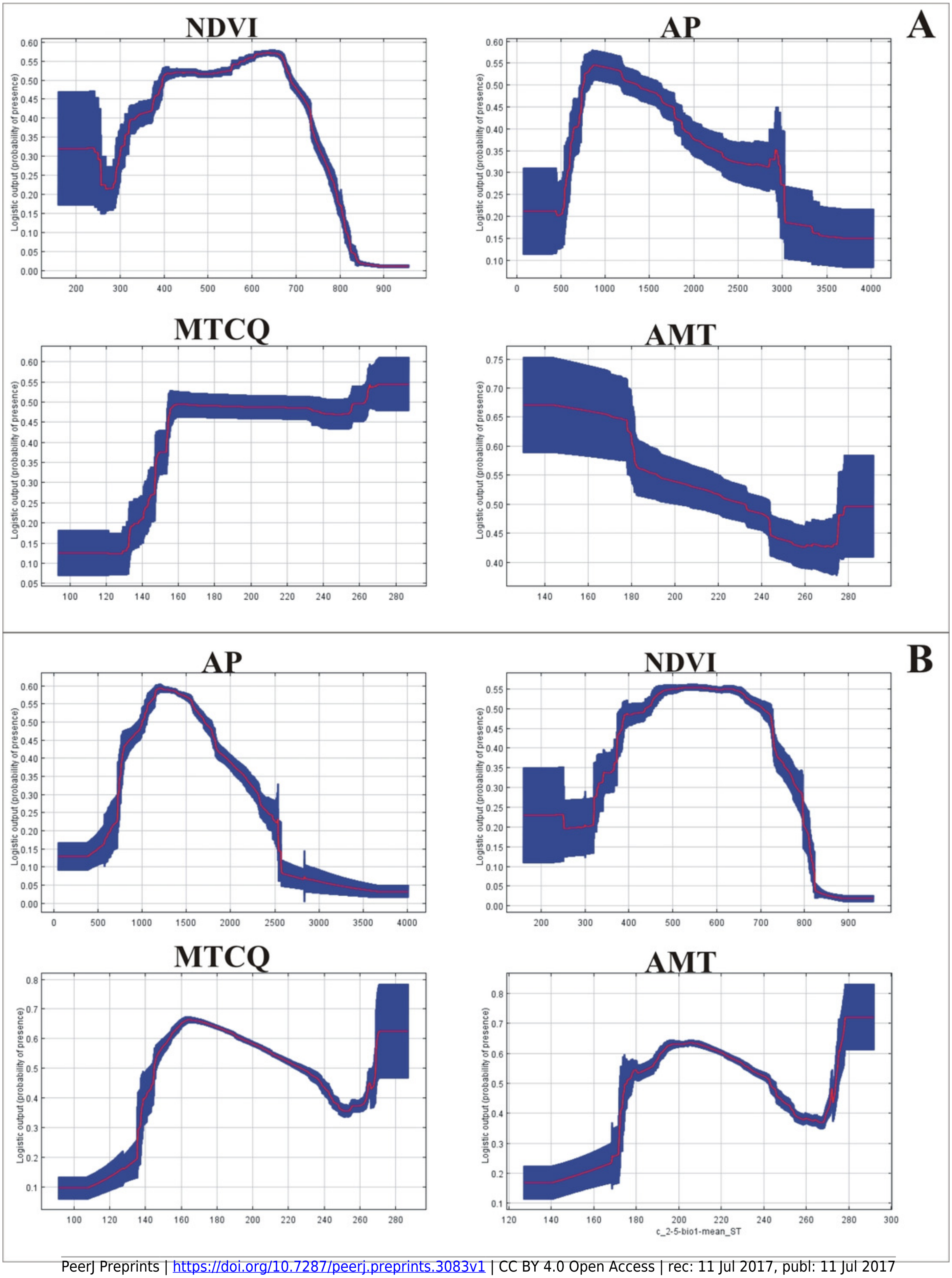
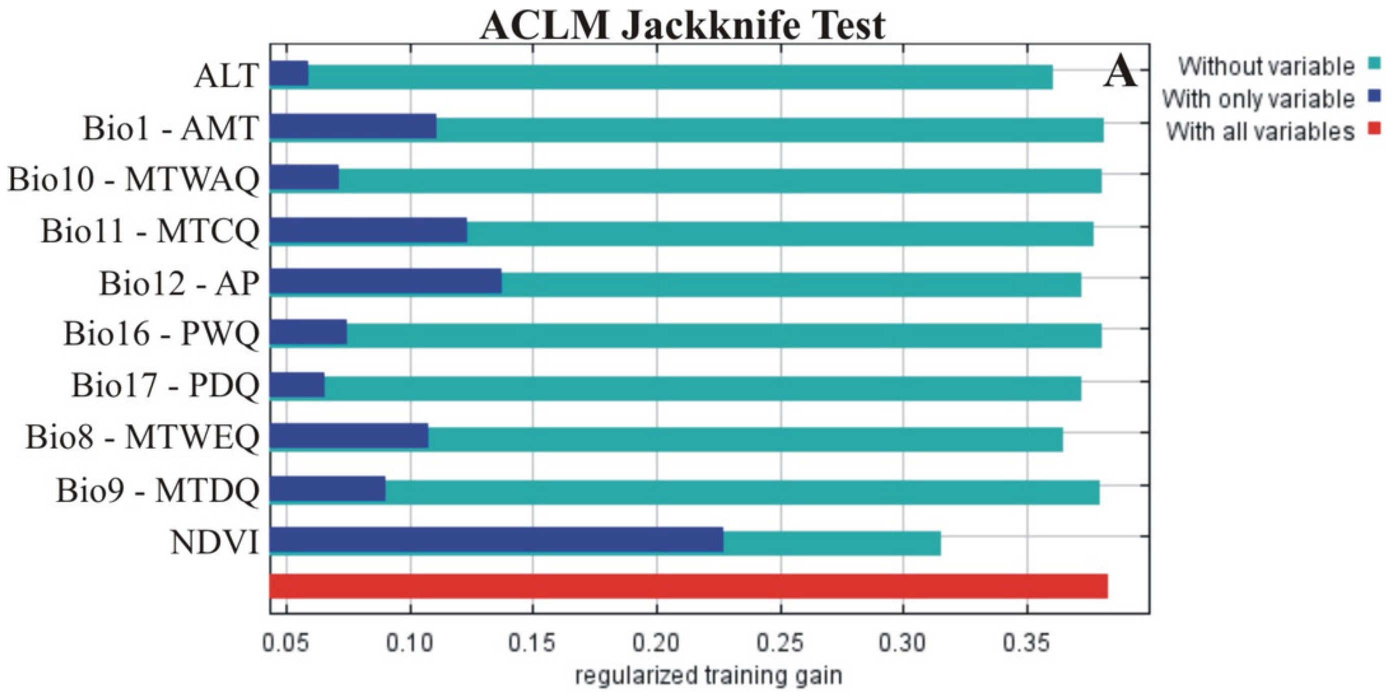

A
NDVI
AP
MTCQ
AMT
B
AP
NDVI
MTCQ
AMT
Logistic output (probability of presence)
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
0.55
0.60
0.65
0.70
0.75
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
200
300
400
500
600
700
800
900
0
500
1000
1500
2000
2500
3000
3500
4000
100
120
140
160
180
200
220
240
260
280
300
c_2-5-bio1-mean_ST

Figure 3

Jackknife test results of individual environmental variable importance in the development of the MAXENT models

Jackknife test results of individual environmental variable importance in the development of the MAXENT models relative to all environmental variables (red bar), for each predictor variable alone (blue bars), and the drop in training gain when the variable is removed from the full model (lighter blue bars). A) American Cutaneous Leishmaniasis Model (ACLM) and B) *Lutzomyia (N.) whitmani* Model (LWM) jackknife test results


ACLM Jackknife Test
A
ALT
Bio1 - AMT
Bio10 - MTWAQ
Bio11 - MTCQ
Bio12 - AP
Bio16 - PWQ
Bio17 - PDQ
Bio8 - MTWEQ
Bio9 - MTDQ
NDVI
0.05
0.10
0.15
0.20
0.25
0.30
0.35
regularized training gain
Without variable
With only variable
With all variables

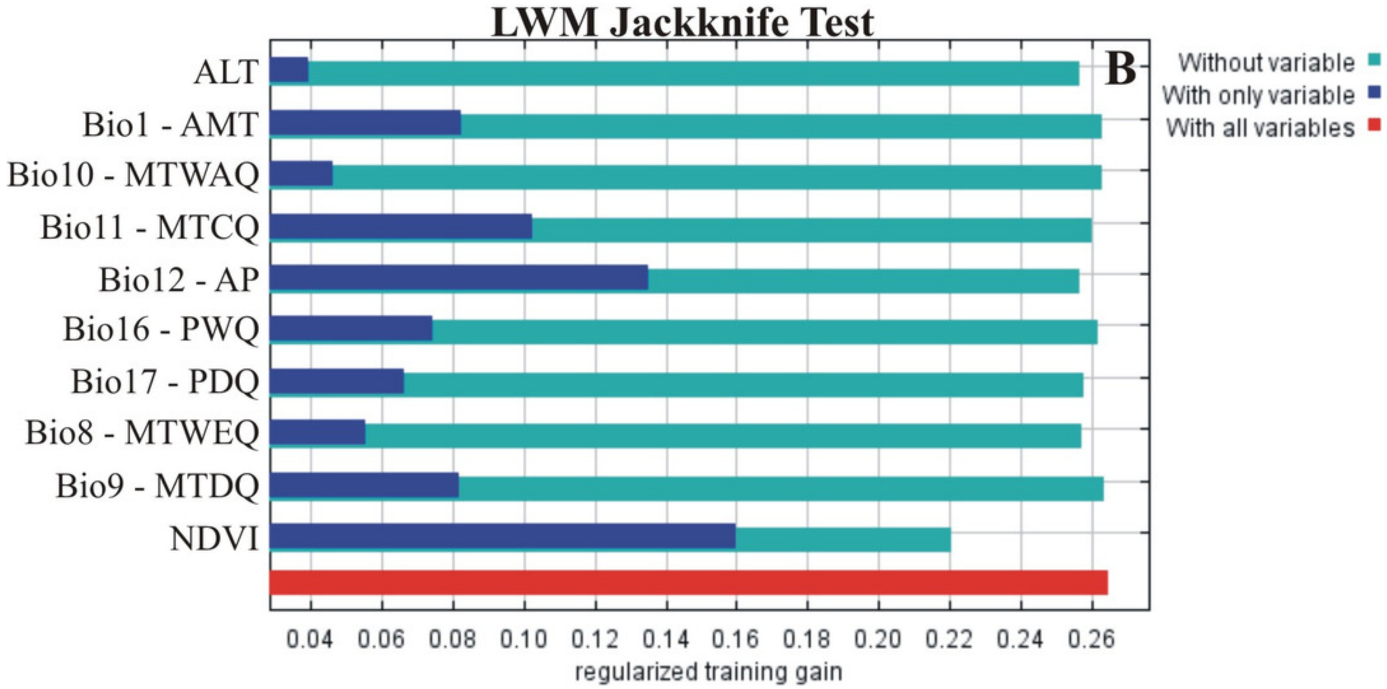

LWM Jackknife Test
B
ALT
Bio1 - AMT
Bio10 - MTWAQ
Bio11 - MTCQ
Bio12 - AP
Bio16 - PWQ
Bio17 - PDQ
Bio8 - MTWEQ
Bio9 - MTDQ
NDVI
0.04
0.06
0.08
0.10
0.12
0.14
0.16
0.18
0.20
0.22
0.24
0.26
regularized training gain
Without variable
With only variable
With all variables

Figure 4

The most dissimilar variables (MoD) between current and future climate scenarios

The most dissimilar variables (MoD) between current and future climate scenarios - i.e., the variable driving the dissimilarity result