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1 A global risk assessment of primates under climate and land use/cover
2 scenarios

3

4 **Running title:** Global change-related risks for primates

5

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22

23 **Keywords**

24 Climate change, exposure, extinction risk, hazard, land use/cover change, primate
25 conservation, primate hotspots, species ranges

26 ABSTRACT

27 Primates are facing an impending extinction crisis, driven by extensive habitat loss, land use
28 change, and hunting. Climate change is an additional threat, which alone or in combination
29 with other drivers, may severely impact those taxa unable to track suitable environmental
30 conditions. Here, we investigate the extent of climate and land use/cover (LUC) change-
31 related risks for primates. We employed an analytical approach to objectively select a subset
32 of climate scenarios, for which we then calculated changes in climatic and LUC conditions
33 for 2050 across primate ranges (N=426 species) under a best- and a worst-case scenario.
34 Generalised linear models were used to examine whether these changes varied according to
35 region, conservation status, range extent, and dominant habitat. Finally, we reclassified
36 primate ranges based on different magnitudes of maximum temperature change, and
37 quantified the proportion of ranges overall and of primate hotspots in particular that are likely
38 to be exposed to extreme temperature increases. We found that, under the worst-case scenario,
39 74% of Neotropical forest-dwelling primates are likely to be exposed to maximum
40 temperature increases up to 7°C. In contrast, 38% of Malagasy savanna primates will
41 experience less pronounced warming of up to 3.5°C. About one quarter of Asian and African
42 primates will face up to 50% crop expansion within their range. Primary land (undisturbed
43 habitat) is expected to disappear across species' ranges, whereas secondary land (disturbed
44 habitat) will increase by up to 98%. With 86% of primate ranges likely to be exposed to
45 maximum temperature increases >3°C, primate hotspots in the Neotropics are expected to be
46 particularly vulnerable. Our study highlights the fundamental exposure risk of a large
47 percentage of primate ranges to predicted climate and LUC changes. Importantly, our findings
48 underscore the urgency with which climate change mitigation measures need to be
49 implemented to avert primate extinctions on an unprecedented scale.

50 INTRODUCTION

51 Global biodiversity is under serious assault due to a host of anthropogenic activities and
52 climate change (Schloss, Nuñez, & Lawler, 2012; Thomas et al., 2004). Climate change could
53 exacerbate the effects of the expected drastic alterations in land use during and beyond the
54 21st century (McClean et al., 2005). In combination, climate and land use/cover (LUC)
55 changes will have negative consequences for many wildlife species, likely driving the
56 extinction of many in the future (Gouveia et al., 2016; Struebig et al., 2015). Thus, when
57 trying to better understand variation in climate-related risks between taxa it is fundamental to
58 consider both the single effects and the synergistic interactions between climate and LUC
59 changes, especially because jointly these global change drivers will pose many challenges to
60 species conservation in the future (Gouveia et al., 2016; Titeux et al., 2017).

61 Studies assessing climate change impacts on biodiversity are geographically biased towards
62 temperate regions, whereas biodiverse tropical and subtropical regions remain understudied
63 (Pacifici et al., 2015). Although less pronounced changes in climate in the tropics than in
64 temperate regions have been forecast, many tropical species have already exceeded their
65 physiological tolerance limits to changing climatic conditions (Schloss et al., 2012),
66 highlighting that more research on tropical species is particularly urgent (Pacifici et al., 2015;
67 Tewksbury, Huey, & Deutsch, 2008).

68 In addition to being charismatic animals, non-human primates (primates hereafter) are
69 considered flagship species in tropical forest ecosystems whose conservation importance
70 cannot be overstressed. Human activities have already taken a severe toll on primate
71 populations, which are dwindling rapidly, as reflected in their alarming status on the IUCN
72 Red List (Estrada et al., 2017). This is despite the fact that some primates show a certain
73 behavioural flexibility enabling them to adapt and survive in human-modified habitats
74 (Estrada et al., 2017; Estrada, Raboy, & Oliveira, 2012; Spehar et al., 2018). Several threats

75 including hunting, habitat loss, infectious disease epidemics, large-scale commercial logging,
76 and industrial agriculture are directly contributing to their decline, while others, such as
77 human population growth and increased per capita demand do so indirectly (Estrada et al.,
78 2017; Lehman, Fleagle, & Tuttle, 2006). Although all of the aforementioned are important
79 drivers of primate declines, ongoing climate change is a delocalized driver, likely contributing
80 to many of these threats (Gouveia et al., 2016; Graham, Matthews, & Turner, 2016; Lehmann,
81 Korstjens, & Dunbar, 2010; Ribeiro, Sales, De Marco, & Loyola, 2016; Wiederholt & Post,
82 2010).

83 Primates occur in four major geographic regions: Neotropics, mainland Africa (hereafter
84 Africa), Madagascar, and Asia, with most species inhabiting tropical moist lowland forests.
85 More than half of all primate species are threatened with extinction, with 62% classified as
86 threatened and 5% listed as near threatened (Supporting Information Table S1). Madagascar
87 and Asia are hotspots of primate extinction risk (92% and 77% of threatened species,
88 respectively), while a comparatively lower percentage of species in the Neotropics and Africa
89 is threatened (44% and 41%, respectively) (Table S1) (Estrada et al., 2017).

90 Climate change is likely to have been an important factor in shaping the evolutionary history
91 of primates (Jablonski, Whitfort, Roberts-Smith, & Qinqi, 2000; Spehar et al., 2018), and is a
92 potential threat to primate populations and to the resilience of protected areas across their
93 range (Africa (Lehmann et al., 2010), Asia (Struebig et al., 2015), Neotropics (Ribeiro et al.,
94 2016) and Madagascar (Kamilar, 2017)). This is either due to its direct effects on primate
95 physiology, or indirectly through its influence on resource availability (Chapman et al., 2005;
96 Isabirye-Basuta & Lwanga, 2008; Wiederholt & Post, 2010). Schloss et al. (2012) assessed
97 the ability of mammals to keep pace with climate change, and found that most mammals in
98 the Amazon will not be able to disperse to suitable climates given the fast pace of forecast
99 changes. Moreover, their study suggested that the predicted magnitudes of climate change

100 might exceed the physiological tolerance limits of many species. Among mammals, primates
101 are likely to be the most vulnerable group as they exhibit a number of traits that make them
102 highly susceptible to climate change, such as slow reproduction, low population densities,
103 dietary requirements, and thermoregulation, which limit their dispersal capacity (Schloss et
104 al., 2012). Accordingly, the Intergovernmental Panel on Climate Change (IPCC) drew
105 attention to primates as the mammalian order with the lowest dispersal speed, underscoring
106 that many species likely face an elevated risk of extinction (IPCC, 2014).

107 Interestingly, a few primate taxa such as baboons occupy very large geographic ranges and
108 show environmental flexibility, which would make them physiologically less vulnerable to
109 climate change (Fuchs, Gilbert, & Kamilar, 2018). Ecological niche models have suggested
110 considerable primate range reductions rather than range expansion or stability, as well as loss
111 of habitat connectivity under climate change (Brown & Yoder, 2015; Gouveia et al., 2016;
112 Meyer, Pie, & Passos, 2014; Struebig et al., 2015). Importantly, loss of habitat and
113 connectivity in combination with climate change may severely impact those taxa unable to
114 track climatically-suitable habitats (Gouveia et al., 2016; Titeux et al., 2017).

115 Patterns of species co-occurrence in primates have been linked to biogeographic history,
116 interspecific competition, predation, and anthropogenic disturbance (Bello et al., 2015;
117 Jablonski et al., 2000; Kamilar, 2017; Spehar et al., 2018). Climate change could be an
118 additional factor shaping sympatric species diversity of primates in the future (Graham et al.,
119 2016; Pacifici, Visconti, & Rondinini, 2018), particularly by altering the structure and
120 composition of their habitats (Isabirye-Basuta & Lwanga, 2008; Jablonski et al., 2000).

121 Understanding how climate change is likely to affect primate hotspots, i.e. areas with highest
122 species richness, is relevant to ensure effective conservation efforts, however, such
123 assessments are currently lacking.

124 Most assessments of future climate change-related risks, LUC change, or their combined
125 effects for primates to date were regional-scale analyses (Brown & Yoder, 2015; Gouveia et
126 al., 2016; Meyer et al., 2014; Ribeiro et al., 2016), relied on earlier, now outdated IPCC
127 climate emission scenarios (Brown & Yoder, 2015; Graham et al., 2016; Meyer et al., 2014),
128 or did not consider mechanistically relevant variables representing seasonal variations or
129 extreme climate change (Graham et al., 2016; Lehmann et al., 2010; Pacifici et al., 2018).
130 Consequently, in this study we expanded on this earlier work and for the first time quantified
131 climate-related risks of all 426 primate species currently available in the IUCN database
132 (IUCN, 2018) to changing climatic and LUC conditions predicted for the year 2050. We
133 modelled variation in hazard (magnitude of projected climate and LUC change) and exposure
134 (likelihood to experience the hazard) risks (IPCC, 2014; Pacifici et al., 2018) in relation to
135 geographic region, conservation status, range extent, and predominant habitat, and quantified
136 the percentage of species ranges and primate hotspots likely to be exposed to extreme climate
137 changes. Specifically, we addressed the following questions: (1) Which regions are likely to
138 be most affected by altered temperature, precipitation and LUC conditions? (2) Will species
139 listed as threatened face greater risks to both global drivers than non-threatened species? (3)
140 Are small-range species more exposed to climate-related risks? (4) Will the synergistic effects
141 between climate change and habitat loss affect forest and savanna primates differently? (5)
142 What proportion of species ranges will be exposed to extreme maximum temperature
143 increases? and (6) What proportion of primate hotspots will be affected by extreme warming?

144

145 **MATERIALS AND METHODS**

146 **Primate data**

147 Data on primate geographic ranges were compiled from the IUCN Red List of Threatened
148 Species database (IUCN, 2018). This database contains 426 primate species from 74 genera

149 and 16 families (Table S1), and also provides information about conservation status (critically
150 endangered (CR), endangered (EN), vulnerable (VU), near threatened (NT), least concern
151 (LC) and data deficient (DD)) and range extent (km²). In addition, for each primate species,
152 we collated information on geographic region (Lehman et al., 2006), and predominant habitat
153 in its range. The latter was extracted from the land cover data provided by the MODIS-based
154 global land cover climatology dataset (Broxton et al., 2014). This dataset integrates global
155 land cover information from 10 years (2001-2010, at ~500 m resolution) and features 16
156 global land cover classes based on a supervised decision-tree algorithm. We reclassified these
157 into three land cover types: forest, savanna, and other (includes shrubland, grassland, wetland,
158 cropland, urban areas and snow), and extracted the average of each habitat type (in km²).
159 Forest and savanna represent the most suitable habitats for primates (IUCN, 2018).
160 All spatial data were standardized to a resolution of 2.5 arc-minutes (~4.5 km at the equator
161 line) and projected into WGS84 Mercator geographic coordinate system. All analyses were
162 performed using the software ArcGIS (ESRI, 2011) and R (R Development Core Team,
163 2018).

164

165 **Climatic variables and climate emission scenarios**

166 Bioclimatic variables (hereafter climatic variables) based on temperature and precipitation for
167 current and future conditions were compiled from WorldClim (periods of 1950-2000 and
168 2050, respectively; version 1.4, available at www.worldclim.org; for more details see
169 (Hijmans, Cameron, Parra, Jones, & Jarvis, 2005)). All climatic variables (N = 19)
170 representing current conditions were extracted for each primate species' range.
171 As adopted by the IPCC for its Fifth Assessment Report (IPCC, 2014), a new set of global
172 climate change scenarios resulting from a combination of general circulation models (GCMs)
173 with mitigation policies regarding greenhouse gas emission scenarios (Representative

174 Concentration Pathways, RCPs (W/m²) were compiled for 2050 (Table S2). RCPs explore
175 alternative technology and land use patterns, as well as socio-economic and climate policy
176 (Moss et al., 2010; IPCC, 2014). These emission scenarios are based on natural and human-
177 driven impacts on future radiative forcings, i.e. changes in the balance of incoming and
178 outgoing radiation to the atmosphere caused by changes in atmospheric components such as
179 carbon dioxide, methane and nitrous oxide (Moss et al., 2010), to describe four different 21st
180 century pathways of greenhouse emissions: RCP 2.6, RCP 4.5, RCP 6.0 and RCP 8.5. RCP
181 2.6 represents a stringent mitigation scenario, RCP 4.5 and 6.0 are intermediate mitigation
182 scenarios, and RCP 8.5 is a low mitigation scenario with very high greenhouse emissions.
183 The IPCC recommends the use of a large ensemble of climate scenarios produced from
184 combinations of 19 GCMs and 4 RCPs, however, many studies to date relied on climate
185 scenarios that were arbitrarily chosen (Baker et al., 2015; Garden, O'Donnell, & Catterall,
186 2015; Thuiller, 2004). Moreover, the magnitude of projected climate change is substantially
187 affected by the choice of emission scenario by mid-21st century (IPCC, 2014). Thus, we used
188 k-means clustering (Casajus et al., 2016) to objectively select a subset of climate emission
189 scenarios. This method decreases the number of climate scenarios to evaluate while retaining
190 the central tendencies and coverage of uncertainty in future climatic conditions. Additionally,
191 it improves the representativeness of climate scenarios at the regional scale by avoiding the
192 common misrepresentation of climate scenarios resulting from an arbitrary selection (Casajus
193 et al., 2016). All GCMs (N = 19) for RCPs 4.5, 6.0, and 8.5 were considered and extracted for
194 each primate species' range. We excluded RCP 2.6 because trends in greenhouse emissions
195 predicted by the other RCPs better represent actual emissions since 2000 (Peters et al., 2011).
196
197 **LUC data and future scenarios**

198 Global LUC data for current conditions and 2050 projections were compiled from the Land
199 Use Harmonization Project (period of 1500-2100, at ~50 km resolution) (Chini, Hurtt, &
200 Frohking, 2014; Hurtt et al., 2011), which smoothly combines LUC history data with future
201 scenario information from multiple GCMs into a consistent gridded set of LUC scenarios.
202 Project outputs informed the IPCC Fifth Assessment Report and LUC scenarios are the same
203 used to derive the climate scenarios. GCMs are combined with RCPs: IMAGE 2.6, MiniCam
204 4.5, AIM 6.0, and MESSAGE 8.5. The very low stabilization scenario IMAGE 2.6 predicts
205 rapid conversion of primary vegetation, especially in the tropics, to crops and biofuels. In
206 contrast, MiniCam 4.5 predicts decrease in both cropland and pasture areas as a result of
207 reforestation programs, crop yield improvements and dietary shifts (Hurtt et al., 2011;
208 Newbold et al., 2015). A decrease in pasture areas as a consequence of more intensive
209 husbandry and increase in cropland due to increasing food demand are predicted by AIM 6.0.
210 Widespread expansion of croplands and pasture areas due to increasing global human
211 population is expected in the high-emission pathway MESSAGE 8.5. All scenarios project an
212 increase in wood harvesting, contributing to large increases in secondary land and,
213 consequently, to large reductions in primary land. For more detailed information on these
214 scenarios see Hurtt et al. (2011) and Chini et al. (2014). Of the five available land use states
215 we selected for this study those that best represent biomes where most primates occur:
216 primary land, secondary land, and cropland. Primary land refers to the natural vegetation
217 (either forest or non-forest) undisturbed by humans, and secondary land corresponds also to
218 natural vegetation previously disturbed by human activities (e.g. agriculture or wood
219 harvesting), but recovering, both since the simulation start year of 1500. Thus, primary land
220 and cropland represent the most and least suitable habitat for primates, respectively, with
221 secondary land occupying an intermediate position.
222

223 **Climate and LUC change-related risks for primates and their correlates**

224 All climate (N = 19) and LUC variables (N = 3) for the current conditions were assessed for
225 collinearity by conducting a spatial principal component analysis (PCA) (R package ‘stats’).

226 The variable with the strongest correlation for the first five principal components was
227 selected. Only 30 future climate scenarios were available for the five climatic variables
228 selected by the PCA (Table S2), and tested with the k-means clustering approach (Casajus et
229 al., 2016).

230 Mean changes in climatic and LUC variables across each species’ range between 2050 and
231 present were calculated. For that, only climatic variables selected in the PCA were considered
232 as well as each climate change scenario selected by the k-means clustering approach.

233 To examine whether risks to changes in climatic and LUC conditions vary according to region
234 (Neotropics, Africa, Madagascar and Asia), conservation status (CR, EN, VU, NT, LC, DD),
235 range extent ($<10 \times 10^3$ km², $>10 \times 10^3$ and $<50 \times 10^3$, $>50 \times 10^3$ and $<25 \times 10^4$, $>25 \times 10^4$ and
236 $<10 \times 10^5$, $>10 \times 10^5$ and $<40 \times 10^5$, and $>40 \times 10^5$) and predominant habitat (forest, savanna, and
237 other), we performed generalised linear models using R package ‘glmulti’ (Calcagno, 2013).

238 This package is optimized to deal with large candidate model sets and provides a flexible way
239 to carry out automated information-theoretic model selection and multi-model inference
240 (Calcagno & de Mazancourt, 2010). A Gaussian distribution with an identity link function
241 was used, specifying interactions between all variables. Non-normally distributed residuals
242 for the climatic variables were corrected using a log-transformation in the models, but
243 untransformed values were used when plotted. For each response variable, a confidence set of
244 candidate models was selected based on the Akaike Information Criterion ($\Delta AIC_c < 2$), and the
245 corresponding model-averaged regression coefficients and Akaike weights were calculated.
246 For each significant effect in the best model for each response variable, the corresponding
247 percentage of species affected was calculated.

248

249 Exposure risk of ranges and primate hotspots to extreme warming

250 Understanding of climate change-related risks is hampered by a lack of knowledge about the
251 precise magnitudes of change, however, it is accepted that risks will increase with rising
252 temperature (IPCC, 2014). According to the IPCC, moderate risks associated with extreme
253 climate change are expected with increases in global mean temperature of 1-2°C above pre-
254 industrial levels, and high to very high risks with temperature rises 4°C or above. To represent
255 different levels of risk associated with climate change, we considered four magnitudes of
256 change in maximum temperature of the warmest month (T_{\max}) (< 2°C, > 2°C, >3°C, and >4°C)
257 under a worst-case scenario (RCP 8.5) to quantify the cumulative percentage of each species'
258 range (total and by family) likely to be exposed to these magnitudes by 2050 and, for each
259 species' range, the number of sympatric primate species. For that, a spatial layer representing
260 changes in T_{\max} across primate ranges was reclassified into the aforementioned four
261 magnitudes of change and then superimposed on the primate ranges to extract the number of
262 pixels within each species' range that corresponded to each category. We further identified
263 those primate species likely to have more than 50% of their range exposed to extreme (>4°C)
264 increases in T_{\max} . Finally, the number of sympatric species was grouped into four classes (1-5,
265 6-10, 11-15, and 16-19) and for each magnitude of change in T_{\max} we quantified the
266 percentage of overlapping range.

267 Previous studies have advocated greater consideration of variation or extremes in climatic
268 conditions when modelling the impacts of climate change on primate distribution (Fuchs et
269 al., 2018; Graham et al., 2016; Ribeiro et al., 2016). We therefore considered T_{\max} as the most
270 suitable proxy variable for assessing climate-change risk, given that high to very high risks
271 are expected with temperature rises 4°C or above (IPCC, 2014), and the same magnitude of
272 change was found for minimum temperature of the coldest month (T_{\min}) and no relevant

273 changes were observed for precipitation of the wettest month (P_{wet}) (see Results). Only a
274 worst-case scenario was considered for these analyses because our main interest here was to
275 inform upstream planning (Lehmann et al., 2010; Ribeiro et al., 2016) and most countries
276 where primates occur are suffering from high levels of corruption and weak governance and,
277 consequently, low mitigation policies regarding climate change (Estrada et al., 2018; IPCC,
278 2014, 2018).

279

280 **RESULTS**

281 **Selection of variables and future scenarios**

282 The PCA captured 84% of the total variance in the first five principal components, which
283 were most strongly correlated with the following variables: T_{min} (-0.32, PC1: 40.6% of
284 variance), T_{max} (-0.38, PC2: 19.7%), P_{wet} (0.52, PC3: 12.5%), *secondary land* (-0.59, PC4: 6.0
285 %), and *cropland and primary land* (-0.56 and 0.56, respectively, PC5: 5.6%) (Table S3).
286 Reduction of 30 climate emission scenarios via k-means clustering resulted in six clusters
287 summarizing 86% of the variance and with sizes between one and six climate scenarios
288 (Table S4, Fig. S1). To simplify the interpretation of the results, and given that some
289 scenarios forecast the same magnitude of change (Fig. S2), below we only contrast predicted
290 outcomes under the best-case scenario (i.e. high mitigation scenario) and the worst-case
291 scenario (i.e. low mitigation scenario) in modelling changes in climatic conditions (CCSM4
292 4.5 (hereafter CC 4.5) and HadGEM-ES 8.5 (hereafter HE 8.5), respectively) and in land
293 use/cover conditions (MiniCam 4.5 and MESSAGE 8.5, respectively) for the year 2050 (Fig.
294 S1, S2).

295

296 **Climate change-related exposure risk of primate ranges**

297 For T_{\max} and T_{\min} , under both scenarios, model selection provided overriding support ($w_i =$
298 0.76-0.96) for region, conservation status, habitat and range size influencing risk exposure.
299 For P_{wet} , region and habitat were identified as key predictors under both scenarios, however,
300 there was some model selection uncertainty, especially for the best-case scenario (Table S5,
301 S6).

302 Primate species will face an increase in T_{\max} and T_{\min} throughout their range of distribution
303 under both scenarios (Fig. 1a,b; Fig. S3). In the Neotropics, an increase of $>2^{\circ}\text{C}$ in T_{\max} is
304 likely, with particularly dramatic increases of up to 7°C expected for Central and Northern
305 Brazil under the worst-case scenario. Forest primates will be the most affected by these
306 changes (74% of all Neotropical species) (Fig. S3; Table 1, S1). An increase in T_{\max} of up to
307 5°C is predicted for southern Africa (23% of all species), as well as for North-East and South-
308 East Asia (23% of all species) under the worst-case scenario (up to 3°C in the best-case
309 scenario). In contrast, under both scenarios, changes are likely less pronounced in Madagascar
310 (up to 3.5°C), particularly for savanna primates (38% of all Malagasy species). Both scenarios
311 also project that primate species with larger ranges are likely to face an increase in T_{\max} .

312 Exposure risk did not vary significantly among species depending on their conservation status
313 under the worst-case scenario while those currently listed as LC (29% of all species) might
314 experience an elevated risk under the best-case scenario (Fig. S3; Table 1, S1).

315 According to the worst-case scenario, T_{\min} is forecast to increase up to 5°C (up to 3°C in the
316 best-case scenario) in all major primate regions, particularly in Central Brazil and Africa, and
317 China (here affecting mostly primates living in less forested habitats, i.e. 18% of all Asian
318 species) (Fig. 1a,b; Fig. S3; Table 1, S1). In contrast, the ranges of Neotropical savanna
319 primates will experience less marked increases of up to $2.5/4^{\circ}\text{C}$ (best-/worst-case scenario;
320 20% of all Neotropical species). Again, Madagascar is likely to face only small increases up
321 to 3°C under the worst-case scenario (up to 1.5°C in the best-case scenario), affecting 51% of

322 non-forest Malagasy primates. Changes in T_{\min} will differentially affect species depending on
323 conservation status, and will influence primates with larger ranges more (Fig. S3; Table 1).
324 The best-case scenario predicts an increase up to 100 mm in P_{wet} across the ranges of Asian
325 and Malagasy primates in less forested habitats (18% and 51% of species, respectively) (Fig.
326 1a, S3; Table 1, S1). In contrast, decreases up to -200 mm are forecast for the same primate
327 ranges under the worst-case scenario (Fig. 1b). Decreases in P_{wet} are likely across most
328 primate ranges in the Neotropics (up to -100 mm), and in some coastal countries in West and
329 southern Africa (up to -150 mm) under both scenarios (Fig. 1a,b; Fig. S3; Table 1, S1). No
330 significant differences in exposure risk with regard to P_{wet} were found for species
331 conservation status or range extent (Table 1).

332

333 **LUC change-related exposure risk of primate ranges**

334 Region and habitat were key correlates of predicted changes in cropland, secondary, and
335 primary land, being included in all best-supported GLMs (Table S5, S6). Most species' ranges
336 are expected to face crop expansion under both scenarios, particularly in West and East Africa
337 (23% of total species) and in most of Asia (21% of non-forest Asian species) where large
338 increases in cropland of up to 50% are likely, and in the South-Eastern Neotropics (31% of
339 total species) with projected increases up to 25% (Fig. 2a,b; Fig. S3; Table 1, S1). Only up to
340 7% crop expansion is expected for Malagasy primate ranges (13% of Malagasy species living
341 in less forested habitats) under the best-case scenario, and up to 25% under the worst-case
342 scenario. Interestingly, under the best-case scenario primate ranges in Central Africa and in
343 the North-Eastern Neotropics might see a substantial reduction of up to 50% in cropland area,
344 in contrast with the forecast increases up to 25% under the worst-case scenario (Fig. 2a,b; Fig.
345 S3).

346 Increases in secondary land are likely to occur in all primate habitats across all regions (up to
347 90% and 60% under the best-case and worst-case scenarios, respectively), with the exception
348 of Madagascar which could face losses up to 60% (affecting 51% of Malagasy species living
349 in less forested habitats) under the worst-case scenario, and West and North Africa with up to
350 40% reduction (23% of total species) under both scenarios (Fig. 2a,b; Fig. S3; Table 1, S1). In
351 contrast, primary land is bound to disappear in most primate ranges, regardless of the scenario
352 (Fig 2a,b). In this respect, most of the Neotropics (up to 98%; affecting most Neotropical non-
353 forest primates, i.e. 26% of all Neotropical species), Africa (up to 95%; African forest
354 primates, i.e. 50% of all African species), and Northern Asia (up to 90%; Asian non-forest
355 primates, i.e. 19% of all Asian species) will suffer the most pronounced changes. Exposure
356 risk to LUC changes was unrelated to range extent, even though primates with larger ranges
357 will be experiencing only mild reductions in primary land compared to those with smaller
358 ranges (Fig. S3, Table1).

359

360 **Exposure risk of ranges and primate hotspots to extreme warming**

361 Under the worst-case scenario, increases $>2^{\circ}\text{C}$ in T_{max} are predicted to affect primates
362 throughout nearly 100% of their ranges (Fig. 3, S4). Large fractions of the ranges of
363 Neotropical (86%) and African (61%) primates are likely to be exposed to $>3^{\circ}\text{C}$ warming,
364 while changes of this magnitude will only affect 36% and 25% of the ranges of Asian and
365 Malagasy primates, respectively (Fig. 3). At the family level, Cebidae and Atelidae in the
366 Neotropics (up to 25% of range) as well as Cercopithecidae in Africa and Asia (up to 38%
367 and 30% of range, respectively) will be those most affected by increases in T_{max} of this
368 magnitude. Extreme ($>4^{\circ}\text{C}$) T_{max} increases are forecast for almost half (41%) of Neotropical
369 primate ranges, in contrast to only 5% for Africa and Asia. Malagasy primates are unlikely to
370 experience such extreme warming (Fig. 3). Again, ranges of the families Cebidae and

371 Atelidae are likely to be the most affected (up to 12%) by such extreme changes. Of the 42
372 species likely to experience an extreme increase in T_{\max} ($>4^{\circ}\text{C}$) in more than 50% of their
373 range 25 are currently listed as non-threatened, however, a considerable fraction ($N = 15$) is
374 already threatened and two are classified as DD (Fig. S4, Table 2). The dominant habitat of
375 these species is forest ($N = 35$), followed by savanna ($N = 6$) and other habitats ($N = 1$), and
376 nearly all of them are Neotropical species ($N = 38$; Asia: $N = 3$, Africa: $N = 1$). Eight
377 Neotropical species are likely to have their entire range exposed to T_{\max} extremes (*Alouatta*
378 *discolour*, *Ateles marginatus*, *Callicebus baptista*, *C. moloch*, *Mico emiliae*, *M. humeralifer*,
379 *M. leucippe*, *Saguinus martinsi*), as opposed to only one Asian species, *Trachypithecus*
380 *laotum* (Fig. S4, Table 2).

381 With up to 19 sympatric primate species, Africa is the world's prime hotspot in terms of
382 primate richness, followed by Madagascar and the Neotropics with up to 15 sympatric
383 species, whereas Asian primate assemblages do not exceed 10 species (Fig. 4). For Africa,
384 those areas where the most primate hotspots occur represent 59% and 34% of primate ranges
385 that are likely to be exposed to increases in $T_{\max} >2^{\circ}\text{C}$ and $>3^{\circ}\text{C}$, respectively, under the
386 worst-case scenario. For Madagascar, the equivalent figures are 40% and 14%, respectively.
387 Primate hotspots for Asia correspond to 29% and 5% of the ranges likely to be exposed to
388 $T_{\max} >3^{\circ}\text{C}$ and $>4^{\circ}\text{C}$, respectively. In contrast, primate hotspots in the Neotropics will be most
389 imperilled, with 53% of ranges likely to be exposed to T_{\max} increases $>3^{\circ}\text{C}$ and 19% to
390 extreme warming ($>4^{\circ}\text{C}$).

391

392 DISCUSSION

393 Although we have presented results both for a high (RCP 4.5) and a low mitigation scenario
394 (RCP 8.5), the latter probably represents the actual situation in most primate regions more
395 accurately due to the weak mitigation policies in place in these countries (IPCC, 2014, 2018;

396 Peters et al., 2011). Moreover, no climate-related mitigation measures have been proposed
397 specifically for primates yet (Korstjens & Hillyer, 2016). To best inform upstream planning,
398 the results are thus discussed primarily under the assumption of a worst-case scenario as the
399 more likely outcome. Our findings suggest that most primate regions will be facing extreme
400 temperature increases, whereby Neotropical forest-dwelling primates will be most affected. In
401 addition, projected decreases in precipitation are likely to affect mostly Asian and Malagasy
402 species that inhabit less forested habitats. Moreover, our analyses indicate that warming will
403 affect species irrespective of threat status and those with larger ranges will be more exposed
404 to anticipated temperature changes, whereas such a pattern was not evident for precipitation.
405 We further found that crop expansion is predicted to invade the majority of primate ranges,
406 particularly in Africa, Asia and the Neotropics. Large increases in secondary land are
407 expected across all regions, while primary land will largely disappear, particularly where
408 primates are confined to forests and where less threatened species are presently found.
409 Neotropical species are likely to be highly exposed to increases in $T_{\max} > 3^{\circ}\text{C}$ in most of their
410 ranges, and several species were identified whose entire range will be exposed to extreme
411 warming ($>4^{\circ}\text{C}$). Finally, half of the area of primate hotspots in the Neotropics is predicted to
412 face warmings $>3^{\circ}\text{C}$.

413

414 **Climate change-related risks for primate ranges due to extreme warming**

415 Our analyses revealed that among all major primate regions, Madagascar is likely to be the
416 one that will be least affected by climate change. In contrast, effects are likely to be most
417 pervasive in the Neotropics, exposing especially forest-dwelling primates to highly elevated
418 T_{\max} across their ranges. Conservation efforts should thus be focused on forest habitats to
419 avert extinctions of Neotropical primates. Many ranges in Africa and Asia are also likely to be
420 affected by climate change, in line with similar broad-scale trends reported by previous

421 studies. For example, Gaffney (2011) suggested that primate ranges in Central America,
422 North-West Africa and South-East Asia will be particularly impacted by climate change.
423 Similarly, Graham et al (2016) found that Central America, the Amazon basin, North and East
424 Africa and East and South-East Asia will be climatically unsuitable for primates in the future.
425 Finally, Ribeiro et al (2016) suggested that species inhabiting the south-western regions of the
426 Neotropics, and particularly Amazonian primates, will probably be unable to keep pace with
427 climate change due to the high velocity of change expected in the tropics and poor dispersal
428 abilities of species (Schloss et al., 2012).

429 Many species are considered to be at very high risk of extinction if exposed to global mean
430 temperatures over 4°C above pre-industrial levels (IPCC, 2014). No studies to date have
431 quantified the thermal limits of primates to global warming, and only few have used thermal
432 indices to assess current climatic data against behavioural data (e.g. Pruetz, 2018; Tagg et al.,
433 2018). Sherwood and Huber (2010) quantified the upper thermal limits in humans through a
434 temperature-humidity index that measures heat stress. They concluded that a global mean
435 warming of about 7°C would be intolerable by humans, given that metabolic heat dissipation
436 would become impossible under these extremes. Moreover, even temperature increases of 3-
437 4°C are likely to surpass the thermal tolerance and to create limitations to cooling in humans
438 (Sherwood & Huber, 2010). Despite the well-known behavioural flexibility of primates to
439 adapt to novel environmental conditions (Estrada et al., 2017, 2012; Fuchs et al., 2018;
440 Spehar et al., 2018), they have relatively limited dispersal abilities for their body size, slow
441 reproduction, low population densities, dietary requirements, and thermoregulation, and many
442 of them might already have surpassed their thermal tolerance to climate conditions. Even if
443 some species migrate to more suitable areas or adapt *in situ*, the current human pressure on
444 primate habitats as well as the predicted reduction of up to 86% of their range with >3°C
445 warming are likely to constrain their dispersal. Thus, we can expect that most, but in

446 particular Neotropical primate species, will be widely exposed to extreme changes in climatic
447 conditions, likely being highly vulnerable to and facing an elevated risk of extinction due to
448 climate change.

449

450 **LUC change-related risks for primate ranges due to extreme warming**

451 Recent global food crises have greatly contributed towards the intensification and major
452 expansion of tropical agriculture (Laurance, Sayer, & Cassman, 2014). Primates will
453 experience future crop expansion throughout most of their ranges, particularly in Africa and
454 Asia where half of primate ranges will be lost due to agricultural expansion (Estrada et al.,
455 2017, 2012; Wich et al., 2014). For the 21st century, Estrada et al (2017) predict that 68% of
456 the current range of primates will be under agriculture. In general, most primary land is likely
457 to disappear and will be replaced by secondary land in up to 98% of primate ranges. Despite
458 the ecological and behavioural resilience of some primate species to cope with anthropogenic
459 habitat modification (Estrada et al., 2017, 2012; Fuchs et al., 2018; Spehar et al., 2018),
460 adverse side effects such as hunting, disease transmission, and human-primate conflicts will
461 exacerbate the vulnerability of primates to LUC change and potentially lead to regional
462 extinctions within their current distribution (Estrada et al., 2018; Gaffney, 2011; Struebig et
463 al., 2015). Moreover, greater increases in habitat loss are expected where climate and LUC
464 changes act synergistically (Gaffney, 2011; Struebig et al., 2015), amplifying the importance
465 of expanding landscape connectivity among areas of suitable habitats for primates to ensure
466 their conservation.

467

468 **Risks to primate hotspots due to extreme warming**

469 Significant losses in terms of primate ranges are likely as a result of anticipated levels of
470 climate change, particularly in the Neotropics and Africa, in line with previous studies

471 (Graham et al., 2016; Pacifici et al., 2015; Ribeiro et al., 2016). Importantly, our study
472 quantified the percentage of range potentially exposed to different magnitudes of T_{\max} change,
473 and $>3^{\circ}\text{C}$ warming is forecast for up to 86% of Neotropical primate ranges, and extreme
474 warming ($>4^{\circ}\text{C}$) for almost half (41%) of their ranges. Ribeiro et al (2016) also predicted a
475 risk exposure up to 3.5°C in more than 80% of Amazon primate ranges under a worst-case
476 scenario. Moreover, our study suggests that primate hotspots in the Neotropics will to a
477 considerable extent (19% of ranges) be exposed to extreme warming ($>4^{\circ}\text{C}$). Pacifici et al.
478 (2018) identified western Amazonia as well as central and eastern Sub-Saharan Africa as
479 important hotspots of mammals, including primates, that face an elevated risk from climate
480 change. Our study thus suggests that allocating effective conservation efforts across their
481 ranges based on primate hotspots is a key approach to minimizing the potential risk of climate
482 change-driven primate extinctions (Graham et al., 2016).

483 Climate and LUC changes will alter patterns of plant species composition and productivity
484 (Chapman et al., 2005), therefore likely leading to a reduction in resource availability for
485 primates (Wiederholt & Post, 2010). This in turn may exacerbate interspecific competition for
486 food (Rocha, Pinto, Boubli, & Grelle, 2015), compromising the persistence of sympatric
487 species and increasing primate vulnerability to climate change as many taxa will be unable to
488 track climatically-suitable habitats (Titeux et al., 2017). For example, Ateline primates are
489 likely to be extremely affected by decreases in resource availability due to extreme climate
490 events (e.g. El Niño) (Wiederholt & Post, 2010). Climate-related mitigation measures for
491 primates are imperative not only to ensure their survival, but because the negative
492 consequences with respect to ecosystem services provided by these flagship species could be
493 irreversible and other functional interactions could be lost (Bello et al., 2015).

494

495 **Strategies to mitigate environmental change impacts on primates**

496 Mitigation, together with adaptation to climate change, is an integrative approach
497 recommended by the IPCC which intends to reduce forecast climate change effects across
498 different temporal and spatial scales (IPCC, 2014, 2018). The most efficient integration of
499 mitigation and adaptation strategies is strictly dependent on policies and cooperation in
500 governance at international, regional, and national scales. Effective conservation actions
501 across primate regions depend on the intrinsic environmental and socio-economic aspects of
502 each country (Estrada et al., 2018). However, lack of law enforcement, weak governance, and
503 economic development locally, and demands for food and forest products globally, will
504 continue to boost pressures on primate populations (Estrada et al., 2018).

505 No climate-related mitigation measures have been proposed specifically for primates yet,
506 however, suggested priority strategies for biodiversity conservation in general which may also
507 be applicable to primates include: forest preservation, restoration, reforestation and
508 afforestation, increasing habitat connectivity, and reintroduction and translocation (Korstjens
509 & Hillyer, 2016). Because deforestation is a major contributor to climate change, global
510 initiatives for effective and sustainable landscape planning to conserve forests and carbon
511 stocks, e.g. through the United Nations REDD + programme, are considered important to
512 expand and connect forested habitats (Lecina-Diaz et al., 2018). Moreover, agroforests can
513 provide important habitats for primates and small-scale agroforestry can contribute to forest
514 conservation and habitat connectivity (Estrada et al., 2012). Finally, translocations and
515 reintroductions of primates need to follow strict guidelines (IUCN, 2012) and should be
516 considered as a last resort.

517 Importantly, most primates are currently distributed in protected areas rich in natural
518 resources (Estrada et al., 2018). Even in the context of limited funding and under growing
519 land use pressure, some protected areas in the tropics have been effective in protecting
520 biodiversity and ecosystems, promoting connectivity, and making a significant contribution to

521 long-term biodiversity conservation (CBD, 2010). However, one-third of protected areas are
522 under intense human pressure globally (Jones et al., 2018). Given that climate change is likely
523 to intensify levels of mobility in human populations (Tacoli, 2009), invasions of climate
524 refugees into protected areas are likely to occur, consequently posing an additional threat to
525 primates. Future studies assessing the effects of climate refugees on protected areas will be
526 central for devising effective conservation strategies that mitigate detrimental impacts on
527 primates and their habitats.

528

529 **Study limitations**

530 Uncertainty in projections of climate scenarios is widely documented (see Sokolov et al.,
531 2009), and considerable efforts have been made to quantify it when predicting anthropogenic
532 global warming either taking into account mitigation policies (IPCC, 2014, 2018) or not
533 (Sokolov et al., 2009). In comparison to past IPCC scenarios, the new set of global climate
534 change scenarios 1) incorporates a substantially larger knowledge base of scientific, technical
535 and socio-economic literature, 2) better characterises the uncertainty in long-term projections,
536 and 3) improves both the simulation of continental-scale surface temperature and large-scale
537 patterns of precipitation (IPCC, 2014, 2018).

538 Importantly, the magnitude of projected changes is markedly affected by the choice of climate
539 scenario, particularly by mid-21st century (IPCC, 2014). In agreement with a trend also
540 reported by Sokolov et al (2009), the worst-case scenario (HE 8.5) considered here forecast
541 changes in T_{\max} of up to 7°C across primate ranges. The best-case scenario, however, also
542 predicted extreme changes in T_{\max} up to 5°C (Fig. S3). Whereas uncertainties persist
543 regarding the magnitude of changes primates will be exposed to in the future, conservationists
544 should not ignore the likely profound effects of this global driver on primates and their
545 habitats, and it is vital that upstream planning take climate change effects into account to

546 minimize future losses of primate species. Our study focused on two key components of
547 climate change-related risks, exposure and hazard, and future work should consider how
548 differences in species' life-history traits and behavioural flexibility affect their intrinsic
549 vulnerability (Lehmann et al., 2010; Pacifici et al., 2018).

550 Finally, the choice of the spatial resolution considered (~4.5 km grid) may explain the
551 differences in results observed for future scenarios. Randin et al (2009) compared the effects
552 of climate change on projected habitat loss at coarse (i.e. European scale, 10x10' grid cells)
553 and local (25mx25m grid cells) scales, and found that all suitable habitats disappeared when
554 forecasting at the coarse scale, whereas most of the suitable habitats persisted at the finer
555 scale. It would be important to consider finer scales in future assessments of the effects of
556 LUC change on primates. This will, however, require future scenarios for global LUC, which
557 incorporate more habitat types than are presently available.

558

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566

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733 Table 1. Results from generalised linear models assessing the effects of region, conservation
 734 status, range extent and dominant habitat on changes in climatic and land use conditions under
 735 the best-case (CC 4.5 and MiniCam 4.5, respectively) and worst-case (HE 8.5 and MESSAGE
 736 8.5, respectively) scenarios. Only results for the best-fit model for each response variable are
 737 shown here. Significant effects are highlighted in bold. See Table S5 and S6 for full model
 738 selection results.

Response variable	Predictors	Predictor levels	Best-case scenario		Worst-case scenario	
			β	SE	β	SE
Max. temperature	Region	Intercept	0.297***	0.031	1.045***	0.025
		Asia	0.084**	0.030	-0.064*	0.031
		Madagascar	0.102**	0.034	0.001	0.035
		Neotropics	0.502***	0.028	0.2659***	0.030
	Conservation status	DD	0.079	0.046		
		EN	0.034	0.026		
		LC	0.116***	0.029		
		NT	0.075	0.040		
		VU	0.040	0.028		
	Habitat	Other	0.049	0.038	-0.067	0.040
		Savanna	0.103*	0.045	0.066	0.048
	Range	Range size**	1.8e-08*	8.4e-09	3.8e-08***	8.2e-09
	Interactions	Asia x Other	0.0200	0.058	0.041	0.062
		Madagascar x Other	-0.038	0.066	0.045	0.070
		Neotropics x Other	-0.350***	0.071	-0.158*	0.075
		Asia x Savanna	0.098	0.105	0.131	0.112
Madagascar x Savanna		-0.130*	0.057	-0.164**	0.061	
	Neotropics x Savanna	-0.453***	0.058	-0.260***	0.061	
Min. temperature	Region	Intercept	0.472***	0.026	1.135***	0.029
		Asia	-0.260***	0.026	-0.247***	0.028
		Madagascar	-0.216***	0.029	-0.442***	0.032
		Neotropics	0.020	0.024	-0.114***	0.026
	Conservation status	DD	0.097*	0.039	0.137**	0.043
		EN	0.060**	0.022	0.010	0.024
		LC	0.082***	0.025	0.038	0.027
		NT	0.096**	0.033	0.033	0.037
		VU	0.050*	0.024	0.052*	0.026
	Habitat	Other	-0.099**	0.032	-0.083*	0.035
		Savanna	-0.108**	0.038	-0.03	0.042
	Range	Range size	2.1e-08**	7.1e-09	2.6e-08***	7.9e-09
	Interactions	Asia x Other	0.194***	0.049	0.122*	0.055
		Madagascar x Other	0.134*	0.056	0.068	0.062
		Neotropics x Other	-0.090	0.0560	-0.035	0.066
		Asia x Savanna	0.204*	0.089	0.311**	0.099
Madagascar x Savanna		0.210***	0.048	0.073	0.053	
	Neotropics x Savanna	-0.086	0.049	-0.178**	0.054	
	Intercept	2.743***	0.125	2.677***	0.148	

Prec. wettest month	Region	Asia	0.386*	0.160	0.218	0.203
		Madagascar	-0.139	0.178	-1.152***	0.286
		Neotropics	-0.938***	0.169	-0.130	0.193
	Habitat	Other	-0.495*	0.211	-0.194	0.280
		Savanna	-0.534*	0.253	-0.819*	0.316
	Interactions	Asia x Other	0.504	0.316	1.103*	0.426
		Madagascar x Other	0.954*	0.389	1.766**	0.626
		Neotropics x Other	1.156*	0.450	0.181	0.512
		Asia x Savanna	1.150*	0.561	0.982	0.676
		Madagascar x Savanna	0.802*	0.315	1.196*	0.573
	Neotropics x Savanna	1.018**	0.345	0.056	0.433	
Cropland	Region	Intercept	-0.010	0.014	0.094***	0.014
		Asia	0.144***	0.013	0.065***	0.014
		Madagascar	0.005	0.015	0.033*	0.016
		Neotropics	0.026*	0.012	-0.061***	0.013
	Conservation status	DD	-0.027	0.020	-0.017	0.021
		EN	0.008	0.011	0.032**	0.012
		LC	-0.004	0.012	0.012	0.013
		NT	0.029	0.017	0.060**	0.018
		VU	-0.026*	0.012	0.005	0.013
	Habitat	Other	0.080***	0.016	0.080***	0.017
		Savanna	0.059**	0.019	0.010	0.022
	Interactions	Asia x Other	0.065*	0.026	0.053	0.027
		Madagascar x Other	-0.085**	0.028	-0.098***	0.029
		Neotropics x Other	-0.018	0.031	0.059	0.033
		Asia x Savanna	0.100*	0.046	0.012	0.049
		Madagascar x Savanna	-0.046	0.025	-0.045	0.026
	Neotropics x Savanna	0.001	0.025	0.100***	0.027	
Secondary Land	Region	Intercept	0.306***	0.025	0.078**	0.027
		Asia	-0.086**	0.332	0.099**	0.034
		Madagascar	0.088*	0.035	-0.348***	0.039
	Habitat	Neotropics	-0.075*	0.030	0.099**	0.033
		Other	-0.273***	0.040	-0.231***	0.044
	Interactions	Savanna	-0.205***	0.048	-0.053	0.052
		Asia x Other	0.288***	0.063	0.242***	0.069
		Madagascar x Other	0.195**	0.068	0.307***	0.074
		Neotropics x Other	0.275***	0.075	0.075	0.082
		Asia x Savanna	0.189	0.113	-0.025	0.123
	Madagascar x Savanna	0.166**	0.061	0.295***	0.067	
	Neotropics x Savanna	0.211***	0.061	0.042	0.067	
Primary land	Region	Intercept	-0.743***	0.028	-0.789***	0.035
		Asia	0.330***	0.035	0.360***	0.035
		Madagascar	0.043	0.039	0.033	0.039
		Neotropics	0.341***	0.034	0.348***	0.033
	Conservation status	DD			0.085	0.053
		EN			-0.047	0.030
		LC			0.037	0.033

	NT			0.025	0.046
	VU			0.007	0.032
Habitat	Other	0.021	0.045	0.022	0.043
	Savanna	0.015	0.053	-0.043	0.052
Range	Range size			-171.9	115.3
Interactions	Asia x Other	-0.208**	0.070	-0.214**	0.068
	Madagascar x Other	0.129	0.075	0.130	0.072
	Neotropics x Other	-0.398***	0.083	-0.421***	0.081
	Asia x Savanna	-0.332**	0.125	-0.108	0.121
	Madagascar x Savanna	0.108	0.068	0.077	0.066
	Neotropics x Savanna	-0.317***	0.068	-0.361***	0.067

739 β : parameter estimates; SE: standard error; *p<0.05, **p<0.01,***p<0.001

740

741 Table 2. List of the primate species likely to be most exposed to extreme climate change,
 742 defined here as those species which are projected to experience increases in the maximum
 743 temperature of the warmest month (T_{\max}) above 4°C in more than 50% of their range under
 744 the worst-case scenario (HE 8.5).

Region/Family	Species	Conservation status*	Current Range (km ²)	Current Habitat	Exposed Range (%)	
AFRICA						
Cercopithecidae	<i>Macaca sylvanus</i>	EN	95,557	other	76.8	
ASIA						
Cercopithecidae	<i>Trachypithecus laotum</i>	VU	5,592	forest	100	
Hylobatidae	<i>Nomascus siki</i>	EN	26,549	forest	67.3	
	<i>Nomascus leucogenys</i>	CR	51,338	forest	66.9	
NEOTROPICS						
Aotidae	<i>Aotus azarae</i>	LC	3,162,698	forest	75.0	
	<i>Aotus trivirgatus</i>	LC	752,040	forest	61.1	
Atelidae	<i>Alouatta discolor</i>	VU	375,736	forest	100	
	<i>Ateles marginatus</i>	EN	524,096	forest	100	
	<i>Alouatta belzebul</i>	VU	866,694	forest	82.1	
	<i>Ateles paniscus</i>	VU	1,061,274	forest	81.8	
	<i>Alouatta macconnelli</i>	LC	1,763,215	forest	67.8	
	<i>Alouatta caraya</i>	LC	3,064,124	savanna	63.9	
	<i>Alouatta nigerrima</i>	LC	236,116	forest	62.5	
Callitrichidae	<i>Mico emiliae</i>	DD	151,986	forest	100	
	<i>Mico humeralifer</i>	DD	63,580	forest	100	
	<i>Mico leucippe</i>	VU	14,839	forest	100	
	<i>Saguinus martinsi</i>	LC	42,109	forest	100	
	<i>Mico argentatus</i>	LC	137,206	forest	99.9	
	<i>Mico rondoni</i>	VU	70,575	forest	97.2	
	<i>Mico intermedius</i>	LC	62,624	forest	97.0	
	<i>Saguinus niger</i>	VU	587,634	forest	84.5	
	<i>Mico melanurus</i>	LC	850,115	savanna	81.9	
	<i>Saguinus midas</i>	LC	863,249	forest	76.3	
	<i>Callithrix penicillata</i>	LC	1,309,803	savanna	74.8	
	<i>Mico mauesi</i>	LC	29,586	forest	66.7	
	Cebidae	<i>Sapajus apella</i>	LC	3,355,096	forest	75.3
		<i>Sapajus libidinosus</i>	LC	2,612,534	savanna	67.6
<i>Saimiri ustus</i>		NT	876,708	forest	65.9	
<i>Cebus kaapori</i>		CR	190,774	forest	62.3	
<i>Saimiri sciureus</i>		LC	4,419,721	forest	55.5	
<i>Sapajus cay</i>		LC	620,932	savanna	51.1	
Pitheciidae	<i>Callicebus baptista</i>	LC	14,741	forest	100	
	<i>Callicebus moloch</i>	LC	944,027	forest	100	
	<i>Chiropotes utahickae</i>	EN	352,113	forest	99.7	
	<i>Callicebus hoffmannsi</i>	LC	92,128	forest	96.3	
	<i>Chiropotes albinasus</i>	EN	981,532	forest	86.3	
	<i>Pithecia pithecia</i>	LC	1,105,061	forest	74.7	
	<i>Chiropotes chiropotes</i>	LC	1,363,870	forest	73.6	

<i>Callicebus pallescens</i>	LC	417,318	forest	73.5
<i>Chiropotes satanas</i>	CR	273,122	savanna	72.4
<i>Callicebus cinerascens</i>	LC	210,384	forest	69.0
<i>Callicebus brunneus</i>	LC	243,776	forest	67.6

745 *CR: Critically Endangered, EN: Endangered, VU: Vulnerable, NT: Near Threatened, LC: Least Concern, DD:

746 Data Deficient

747

748 Figure 1. Projected changes in climatic conditions across primate ranges for 2050. Results are
749 only shown for the best-case scenario and worst-case scenario chosen to represent each
750 climatic variable in the future: CC 4.5 (i.e. CCSM4 RCP 4.5) and HE 8.5 (i.e. HadGEM-ES
751 RCP 8.5), respectively.

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753

754 Figure 2. Projected changes in land use/cover (LUC) conditions across primate ranges for
755 2050. For each LUC variable, the results are shown for the best-case scenario (MiniCam 4.5)
756 and worst-case scenario (MESSAGE 8.5).

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758

759 Figure 3. Cumulative percentage of range (total and by family) within each region likely to be
760 exposed to different magnitudes of change in the maximum temperature of the warmest
761 month (°C) under the worst-case scenario (HE 8.5) for 2050.

762

763

764 Figure 4. Percentage of primate range (by region) likely to be exposed to different magnitudes
765 of changes in the maximum temperature of the warmest month (°C) under the worst-case
766 scenario (HE 8.5) for 2050 across the different classes of primate species diversity (1-5, 6-10,
767 11-15, and 16-19 sympatric species).

768