1   **Climatic niche dynamics and its role in the insular endemism of *Anolis* lizards**

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12   **Running title:** Climatic niche dynamics in *Anolis* lizards

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14

15   **Abstract:**

16   We evaluated the tempo and mode of climatic niche evolution in the radiation of Caribbean

17   *Anolis* lizards and the role of climate in shaping their exceptional insular endemism. Using

18   phylogenetic comparative methods, climatic niche data and a calibrated phylogeny, we

19   reconstructed climatic niche dynamics across time and space for Caribbean *Anolis* lizards. We

20   found evidence of several instances of niche shifts through the Caribbean *Anolis* radiation.

21   Caribbean anole species have diversified mainly along a precipitation rather than a

22   temperature gradient. Only a few lineages have colonized both cold and hot conditions.

23   Furthermore, most of the single-island endemic species are climatically restricted to its native

24   islands and a small set of species might the potential to colonize other islands given its

25   climatic niche requirements. Overall, we found evidence that climate niche conservation has

26   played a role structuring current insular *Anolis* endemism. The observed climatic dissimilarity

27   across the Greater Antilles likely limit successful population establishment of potential exotic

28   insular species.

29

Introduction

Insular systems are a well-known example of unique diversity in biogeography, one that is reflected in an elevated number of endemic species (MacArthur & Wilson, 1967; Losos & Ricklefs 2010). High insular endemism results from a combination of factors, such as colonization, speciation, island size, isolation and environmental uniqueness (Kier *et al*., 2009). Recently, some studies started to take speciation into account as the main driver of island endemism (Kisel & Barraclough, 2010; Qian & Ricklefs, 2012). However, little is known about the role of ecological niche dynamics, understood as the balance of niche conservatism (i.e., the tendency of species to retain ancestral ecological niche traits; Wiens & Graham, 2005) and niche shifts on shaping patterns of island diversity and endemism (Hosner *et al*., 2014).

Ecological niche theory predicts that species' geographical ranges at coarse-grain scales are constrained by a set of abiotic and biotic factors, and dispersal limitations (Peterson *et al*., 2011). For insular species, geographical range is thought to be constrained by strong dispersal barriers rather than biotic or environmental factors (Brown & Lomolino, 1998). However, few tests have been conducted to disentangle the importance of geographical and ecological barriers on the range limits of insular endemic species. Consequently, it is still unknown whether single-island endemic species might encounter suitable ecological niche conditions outside their native areas and therefore what factors drive their current distribution in insular systems.

Niche conservatism and niche shifts patterns emerge as two non-mutually exclusive patterns from ecological niche dynamics along time and across space (Donoghue & Edwards, 2014). These two patterns might contribute to explain the high degree of endemism in many insular systems. For instance, if insular diversity is shaped only by dispersal events, the species colonizing an island might exhibit similar climate requirements (i.e., an environmental filter can limit dispersal events). This niche similarity might either be the result of niche conservatism or niche convergence because of evolving towards similar climate regimes (Boucher *et al*., 2011). In contrast, if insular diversity is shaped only by *in situ* speciation, species might exhibit higher niche similarity because of niche conservatism and niche shifts might eventually occur because of climatic opportunity (Algar & Mahler, 2015). In addition, for insular clades some recent studies have found evidence of a direct link between climate and diversification (Algar & Mahler, 2015; Velasco *et al*., 2016), but still it is not clear how

62   phylogenetic niche conservatism (PNC) or niche divergence pattern can mediate species

63   diversification and ultimately shape species richness and endemism patterns. Using modern

64   phylogenetic comparative methods, it is possible to discern between the two evolutionary

65   scenarios: niche conservatism and niche shifts (Mahler *et al.*, 2013; Bravo *et al.*, 2014).

66   Although there is theoretical evidence that multiple evolutionary processes can drive niche

67   similarity (Revell *et al.*, 2008), the distinction between these two patterns is a crucial step

68   toward understanding how ecological niches evolved at coarse scales and how the two patterns

69   affected insular species richness and endemism patterns.

70   *Anolis* lizards offer a well-known example of adaptive radiation in both insular and

71   mainland settings (Losos, 2009). Insular anole diversity in the Caribbean basin is explained by

72   a combination of geographic, ecological and evolutionary factors (Losos, 2009). Caribbean

73   anole species are notably endemic to a single island with a few species having colonized other

74   islands mediated by human activities (Helmus *et al.*, 2014). This exceptional endemism is

75   reflected in high species turnover rates between islands and is explained by geographic and

76   environmental factors (Stuart *et al.*, 2012). However, climatic niche dynamics might help

77   explain how these exceptional patterns emerged. While it is known that dispersal and available

78   climate space can drive species diversification in insular systems (Bacon *et al.*, 2012; Wuest *et

79   al.*, 2015; Velasco *et al.*, 2016), these factors have not been explored as drivers of *Anolis*

80   endemism in the Greater Antilles.

81   Here, we evaluate how climatic niches have evolved through time and space in

82   Caribbean *Anolis* lizards and how niche continuum process (niche conservatism-niche

83   divergence) can help to explain the exceptional endemism observed today. We address

84   whether anole lineages have converged to similar climate regimes in different islands (niche

85   convergence) and how niche disparity accumulated through radiation. In addition, we

86   evaluated the degree to which climate has played a role in shaping current distributions of

87   single-island endemic species.

88   **Materials and Methods**

89   ***Phylogenetic estimation and divergence times***

90   We used a time-calibrated (MCC-tree) phylogeny from Poe *et al.*, (2017). We excluded

91   all mainland species from this tree and the pruned Caribbean tree was composed of 141

92   species from a total of 166 currently recognized for the Caribbean islands (Poe *et al.*, 2017).

93   The remaining 25 species were not included in this tree due to the lack of molecular data.

94   Anole trees are available from http://www.stevenpoe.net/publications.html

95   ***Climatic niche convergence and niche disparity through time***

96   We compiled the occurrence records for 141 Caribbean *Anolis* from an updated

97   database of 24,074 locality records for *Anolis* species compiled from several sources (e.g.,

98   Algar & Mahler, 2015; Global Biodiversity Information Facility -GBIF-; and original

99   descriptions). We careful revised each species and eliminated erroneous and doubtful records.

100   We extracted climate information for annual mean temperature (bio1) and annual precipitation

101   (bio12) from the WorldClim database (Hijmans *et al*., 2005) for the locality record of each

102   species and calculated the average for species. We used only these two variables to build the

103   occupied climate space for Caribbean *Anolis* lizards. We preferred to use these two direct

104   variables instead scores from ordination methods (e.g., Principal Component Analyses -PCA-)

105   because the interpretation of occupied climate space is straightforward.

106   We tested whether climatic niche variation in Caribbean anole lineages is consistent

107   with a scenario of adaptive convergence. We used the SURFACE program (Ingram & Mahler,

108   2013), which uses a phylogeny and niche traits, to fit an Ornstein-Uhlenbeck (OU) model in

109   which lineages evolved toward convergent climate regimes (adaptive peaks) in a

110   macroevolutionary landscape. An OU model describes an evolutionary process that includes

111   two components: a deterministic tendency to evolve toward optimal states (i.e., adaptive

112   regimes), and a stochastic component that is interpreted as evolutionary changes by natural

113   selection and genetic drift (Butler & King, 2004). The method makes it possible to identify the

114   maximum number of convergent adaptive peaks without any *a priori* delimitation. SURFACE

115   starts with a model with a single adaptive regime for all species and then increases the number

116   of adaptive regimes using a stepwise model selection procedure based on the corrected Akaike

117   Information Criterion (AICc). A new peak shift is added at each step to improve the fit of the

118   model (forward phase). In the backward phase, the final set of previously identified regimes is

119   collapsed to find further improvements of model fit. SURFACE finds the maximum number

120   of adaptive regimes that best fit the data and identifies which clades are convergent towards

121   the same adaptive peaks. We then tested whether our convergent pattern for climatic niche

122   differed from one expected by a null Brownian motion model (BM). We compared our

123   observed convergence parameter (delta k) with 500 simulated delta k under a BM process. We

124   also evaluated the effect of phylogenetic uncertainty on parameter estimation, performing the

125   same analysis as above using a posterior distribution sample of 805 trees.

126   We examined how the niche trait space was occupied by Caribbean *Anolis* lizards during

127   its diversification using disparity through time (DTT) plots (Harmon *et al*., 2003). DTT plots

128   estimate the average niche disparity among subclades relative to the total disparity in the

129   entire phylogeny and we compared this observed trajectory against a mean expectation from a

130   null model generated under Brownian motion. The disparity was calculated as the average

131   pairwise Euclidean distance for each niche trait for the entire tree and then for subclades

132   defined by nodes on that tree. Values approaching 0 indicate that niche variation is partitioned

133   as among-subclade differences, suggesting that subclades exhibit little niche variation in

134   comparison with the entire clade. Conversely, values approaching 1 indicate that subclades

135   contain substantial niche variation and can exhibit a high niche overlap occupying similar

136   regions in climatic space (i.e., niche convergence). Finally, it computes a niche disparity index

137   (NDI; MDI in Harmon *et al*., 2003) as the overall difference in the relative disparity of a clade

138   compared to a null hypothesis simulated with a Brownian motion model. Negative NDI values

139   indicate disparity is less than expected under a Brownian motion null model. These negative

140   values have been interpreted as disparity accumulated early in the history of a clade (i.e.,

141   early-burst trait model). In contrast, positive NDI values indicate disparity is greater than

142   expected under a null model, suggesting that subclades overlap more in their occupation of

143   ecological niche space (Harmon *et al*., 2003). Here, we generated DTT plots for species' niche

144   mean position and calculated the NDI index using the MCC-tree. We compared the NDI index

145   against a mean expectation of 1000 simulated values under a BM model.

146   ***Ecological niche modeling***

147   We generated ecological niche models across the entire Caribbean region for 72

148   species. First, we estimated potential geographical distributions for each species across the

149   Greater and Lesser Antilles islands using three algorithms (GAM: Generalized Additive

150   Model; SRE: Surface Range Envelope; and MaxEnt: Maximum Entropy) implemented in the

151   Biomod2 library in R (Thuiller *et al*., 2009). We used all 19 bioclimatic variables from the

152   WorldClim database with a resolution of 30 arc-seconds (Hijmans *et al*., 2005) and default

153   model parameters. Validation metrics for each model showed that Maxent models had the

154   higher scores and we decided to use this algorithm for the following procedures (Figure S1).

155   We generated potential geographical distributions in Maxent models using 50 pseudo-

156 replicates by splitting the dataset into training (75%) and testing (25%) sets of occurrence

157 points. Binary predictions (i.e., presence-absence) were generated using the 10th percentile

158 threshold as a cut-off (Liu *et al*., 2005). Pixels predicted as present were classified as native

159 (occupied sites) or target (non-occupied sites) given the current native distribution for each

160 *Anolis* species modeled (Losos, 2009).

Climatic niche structure in single-island endemics

162   For each potential geographical distribution, we characterized its environmental

163 suitability using climate information from all 19 variables from Worldclim (Hijmans *et al*.,

164 2005). We extracted climatic information for each pixel defined as a presence from the binary

165 predictions and then each variable was standardized. We calculated the Euclidean distance

166 from each pixel to the niche centroid, which represents the most suitable conditions for a

167 species, and suitability decreases as distances to the niche centroid increase (Maguire, 1973;

168 Martínez-Meyer *et al*., 2013; Lira-Noriega & Manthey, 2014). If climatic niche conservatism

169 played a role in the distribution of single-island endemic species, we expected to find shorter

170 Euclidean distances within native areas than target areas. We compared Euclidean distances

171 between source islands versus target islands controlling for the potential confounding factors

172 of island area and distance between islands. Also, we compared suitability values from

173 continuous Maxent outputs between native and target islands controlling by area and distance.

174   We estimated climate similarity (E-space) between the Caribbean islands with the aim

175 to establish how much of its climatic conditions were unique or shared between islands. If

176 each island exhibits unique climate conditions, this likely have limited the potential successful

177 colonization of other invading species. The similarity between native and target islands was

178 evaluated with the multivariate environmental similarity surface metric (MESS; Elith *et al*.,

179 2010) for each species across the Caribbean region. Negative values in MESS represent non-

180 analog climate conditions (i.e., novel climate conditions) and positive values represent analog

181 conditions (i.e., similar climate conditions). We expected to find negative values outside

182 native areas as a proxy of unsuitable conditions for successful population establishment.

Phylogenetic signal in potential colonization ability

184   We classified species for which we modeled their ecological niches according to their

185 potential successful colonization ability given the predicted climate conditions outside their

186 native areas. Whether species exhibit similar or large Euclidean distances (calculated through

187   a one-tailed t-test) between target and native islands, we coded these as potential to population

188   establishment regardless the ocean barriers to dispersal. In contrast, whether species exhibit

189   small Euclidean distances or not predicted any pixels outside their native areas, we coded

190   these as restricted by climate to its native areas. We used this new binary trait (colonizing

191   ability vs. non-colonization ability) and measure its phylogenetic signal using the D-statistic

192   (Fritz & Purvis, 2010), a measure of phylogenetic signal in a binary trait, with the *caper* R

193   package (Orme *et al*., 2013).

Results

Climatic niche convergence and niche disparity through time

196   The best final model included 29 regime shifts ($k = 29$), 11 distinct regimes ($k' = 11$)

197   and 27 convergent shifts (c =27) occupied by multiple lineages (Figure 1; Table 1). We

198   discovered nine (9) convergent climate regimes (colored large dots) and two (2) non-

199   convergent regimes (black or gray large dots; Figure 1). Most niche shifts discovered by

200   SURFACE suggest that incursions in climate space have occurred along the precipitation axis.

201   Only three lineages evolved by convergence to occupy cold climate regimes (red dots, Figure

202   1). It is likely that many niche shifts are associated with dispersal across islands. For instance,

203   the *roquet* series of *Anolis* lizards (*A. luciae, A. bonairensis, A. griseus, A. trinitatis, A.*

204   *richardi, A. aeneus, A. extremus,* and *A. roquet*) evolved to occupy a wet and hot climatic

205   regime (light blue points, Figure 1). Similarly, four species independently evolved to occupy

206   very rainy conditions in the climate space (*A. occultus, A. cuvieri, A.gundlachi,* and *A.*

207   *evermanni*; light green dots, Figure 1). Finally, at least four lineages have evolved to occupy

208   very hot and dry conditions (*A. bonairensis*, *A. smallwoodi, A. strahmi, A. longitibialis,* and *A.*

209   *ravitergum*; ocher color dots, Figure 1). The resulting pattern of climatic niche convergence is

210   different from an expected by a Brownian motion process (*p*-value < 0.01). A similar pattern

211   of niche shifts across were identified using the *l*lou method (Khabbazian *et al*., 2016; Table

212   S1, Figure S2).

213   The rate of adaptation to optima (α) for temperature was 0.660 and for precipitation

214   was 0.628. Conversely, the rate of stochastic evolution (σ^2) was higher for precipitation

215   (5035.9) than for temperature (1.059). The expected time to evolve halfway to an optimum,

216   calculated in millions of years ($t_{1/2}$ or $\log(2)/\alpha$), was similar for both climate axes

217   (temperature = 1.05 and precipitation = 1.10).

218   The plots of disparity over time for temperature and precipitation exhibited different

219   trajectories through the Caribbean *Anolis* radiation. Niche disparity for temperature was

220   different than expected under a Brownian motion model (left panel in Figure 2). Niche

221   disparity for precipitation exhibited a trajectory different than expected under a Brownian

222   motion model, but the disparity values were highly positives (right panel in Figure 2). For the

223   for temperature and precipitation the niche disparity values calculated for all the tree were

224   positive (temperature NDI=0.151, p<0.00; precipitation NDI=0.471; p<0.001).

Climatic niche structure in single-island endemics

226   Target islands (non-occupied islands) exhibited higher values in Euclidean distances to

227   niche centroid than native islands in single-islands (p-value < 0.001; Figure 3). From 73

228   species used in these analyses, only 14 species showed that target and native islands did not

229   differ in their Euclidean distances to niche centroid (Table S2). Based on this result, we coded

230   species as with potential to colonize other islands and species limited by available climatic

231   conditions. The phylogenetic signal of this binary trait was low (D-statistic = 0.36; p-value =

232   0.014). However, this D-statistic value was not different from an expected by a null Brownian

233   motion model (p-value=0.22).

234   MESS analyses showed that novel climate conditions (i.e., negative values) are

235   spatially concentrated outside native islands for single-endemic anole lizards (p-value < 0.001;

236   Figure 3). Finally, suitability values from Maxent models showed that single-island endemics

237   tend to exhibit low values outside their native areas (p-value < 0.001; Figure 3).

Discussion

239   Climatic niche convergence and niche conservatism have been two very pervasive

240   patterns throughout the Caribbean *Anolis* radiation. Our results show that climatic niche

241   disparity (i.e., niche divergence) has decreased over time. Also, we detected several instances

242   of niche convergence through time (i.e., dispersed through the entire anole phylogeny) and

243   across space (i.e., among islands). These niche convergence events likely occurred as species

244   dispersed or were isolated at the major Caribbean landmasses (Losos, 2009).

245   Both climatic niche stasis and shifts apparently have been recurrent across the entire

246   Caribbean anole radiation. For instance, the *Ctenonotus* clade distributed in Lesser Antilles (*A.*

247   *bimaculatus* group) has retained its ancestral niche occupying a hot and dry climate regime

248   (Figure 1). However, some species in this group (e.g., *A. oculatus*) evolved to occupy cooler

249 and humid conditions than its most recent common ancestor. Some niche shifts are likely

250 associated to dispersal events between islands or within islands.

251   Recent divergence time estimates for *Anolis* lizards suggest that anoles colonized the

252 Caribbean islands (or GAARlandia; Poe *et al*., 2017) before the Eocene-Oligocene glacial

253 maximum. During that time, the global climate was warmer and drier than it is today (i.e., the

254 Middle Miocene Climatic Optimum; Zachos *et al*., 2008). Anoles likely evolved toward cooler

255 and wetter climate conditions after they colonized the Caribbean landmasses and as clades

256 isolated due to the break-up of Caribbean landmass likely occupied available climate spaces

257 quickly in each island (Velasco *et al*., 2016). Parameter estimates of SURFACE showed that

258 the rate of evolution in the thermal niche dimension was slower than hydric one. This suggests

259 that anoles have been more labile to occupy a precipitation gradient than a temperature

260 gradient in the Caribbean islands. Disparity trends suggest that niche evolution has been

261 pervasive across the entire radiation showing higher values than expected under a BM model.

262 Rapid niche evolution can be facilitated by dispersal between and within islands. A previous

263 study found that rates of climatic niche evolution vary with the geographical area and climate

264 heterogeneity (Algar & Mahler, 2016)

265   The observation that several clades of Caribbean anoles diversified extensively in

266 isolation and converged to occupy similar niches suggests that this might be the result of

267 adaptation towards similar environmental regimes (Boucher *et al*., 2011). It is likely that

268 strong stabilizing selection would operate in climatic niches in these single-island endemics

269 (Holt & Gaines, 1992; Holt, 1996). This is supported by our finding that optimal

270 environmental requirements for single-island endemics were low and scarce outside their

271 native islands. This supports the hypothesis that climatic niche adaptation has been pervasive

272 across Caribbean anole radiation and has played an important role in shaping the exceptional

273 insular endemism observed today: only 16 out of 166 species have colonized more than one

274 island (Helmus *et al*., 2014). Finally, the observed niche shifts towards cooler temperatures in

275 the Caribbean region seem to represent an independent evolutionary adaptation. These

276 independent adaptations in some lineages toward cooler conditions have been faster, as in the

277 *cybotes* clade in Hispaniola (Muñoz *et al*., 2014).

278   Regarding the recent criticism that Akaike information criterion (AIC) tends to inflate

279 the false rate of discovery of convergent regimes in comparative datasets (Khabbazian *et al*.,

280 2016), we consider that the alternative procedure presented by Khabbazian *et al*., (20016)

281 based on a Bayesian information criterion (BIC) tends to penalize in excess model complexity
282 (underfit) and therefore always selects very conservative convergent regimes. Because AIC
283 and BIC are based on different philosophies and mathematical formulation, it is not surprising
284 that they select different models. As our aim here is discovery (i.e., prediction), we consider
285 that AIC is a good criterion for this purpose. Regardless, using AIC in SURFACE and *l*ou, we
286 recovered very similar convergent climatic regimes in Caribbean *Anolis* lizards.

287 Finally, we acknowledge that our niche estimates are based on occurrence data and
288 therefore are only an approximation to the fundamental niche (Hutchinson, 1957; Soberón,
289 2007). Although some researchers argue that estimates of physiological tolerances (e.g.,
290 critical thermal maximum and minimum) would be a better approach to evaluate niche
291 dimensions; however, these parameters do not capture the true fundamental niche either,
292 because this can only be estimated using *in situ* population growth rate information (Pulliam,
293 2000; Holt, 2009). Accordingly, it would be necessary to establish whether occurrence data or
294 physiological tolerance limits more closely estimate the Hutchinsonian fundamental niche.

295 ### *Caribbean anole endemicity*

296 Recent work on anole biogeography have shown that dispersal has prevailed in the
297 evolutionary history of Caribbean anoles (Poe *et al*., 2017). Most inferred past dispersal events
298 have occurred when Caribbean islands were merged in a single landmass (Poe *et al*., 2017).
299 Conversely, recent dispersal events across the ocean have been facilitated by humans (Powell
300 *et al*., 2011; Helmus *et al*., 2014). In these recent cases, impoverished islands in anole diversity
301 have been easily colonized by different anole species (Helmus *et al*., 2014).

302 These results suggest that dispersal ability might be prevalent in insular anole lizards,
303 but ocean barriers to dispersal have limited the successful colonization of more Caribbean
304 islands. Our results might contradict this idea and suggest that not all species have the capacity
305 to colonize other islands regardless the geographic barriers. Our results suggest that
306 environmental suitability tend to be limited outside native islands for many single-island
307 endemic *Anolis* species. In addition, MESS analysis also suggests that each Greater Antillean
308 island exhibits a unique set of climatic conditions (Williams & Jackson, 2007; Velasco *et al*.,
309 2016) which would limit the establishment of potential colonizers. The D-statistic showed that
310 phylogenetic signal in the potential ability to colonize given the availability of suitable climatic
311 conditions was low and suggests a phylogenetic clumping (Fritz & Purvis, 2010). This implies

312   that climatic suitability beyond native areas can be predicted by phylogenetic affinity as it has

313   been found with morphological traits (Latella *et al*., 2011; Poe *et al*., 2011)

314   Although single-island endemics might have truncated climatic niches (i.e., species with

315   larger niches than observed but truncated by geography), their niche requirements are also not

316   available in the surrounding geography, as the climatic similarity metrics revealed (Figure 3).

317   However, our results suggest that small Caribbean islands or banks might be good candidates

318   for the establishment of colonizing species because they tend to hold higher values of climatic

319   suitability (Petitpierre *et al*., 2012). All these results suggest that climatic suitability has played

320   an important role, coupled with ocean barriers, in limiting the successful colonization of species

321   to other islands. Many invasion events occurring in small islands (Helmus *et al*., 2014, 2016)

322   and a few in large islands (e.g., *A. sagrei* in Jamaica) support this conclusion. However, we

323   recommend that other approaches, either based on physiological tolerances or demographic data

324   (Kearney & Porter, 2009; Kolbe *et al*., 2014) should be implemented to corroborate or not our

325   results about novel climates limiting dispersal and successful population establishment in the

326   Greater Antilles.

327   ***Conclusions***

328   Our results suggest that climatic niche divergence occurred early in the Caribbean

329   *Anolis* radiation involving multiple episodes of niche shifts, particularly six large events of

330   climatic niche convergence. Caribbean anoles have evolved repeatedly across the climate

331   space occupying different combinations of temperature and precipitation. Multiple lines of

332   evidence suggest that niche divergence has been pervasive along time and across space, but

333   more recent niche conservatism is likely to have played a role driving insular endemism in

334   *Anolis* lizards due to climatic dissimilarity across the Caribbean islands. A next step requires

335   corroborating these main finding using other experimental or modeling approaches and test

336   whether climate dissimilarity also has operated as a driver of insular endemism in other

337   taxonomic groups. We consider that a combination of approaches provides stronger lines of

338   evidence for testing hypotheses about the causes of insular endemism.

339   **Acknowledgments**

347

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472

473 **TABLES**

474

475 Table 1. Convergence parameters from each regime identified by SURFACE in the backward

476 phase (19 regimes) based on the Akaike Information Criteria. AICc: corrected Akaike

477 Information Criterion; Δ AICc: corrected Delta Akaike Information Criterion; k': Number of

478 distinct climate regimes after collapsing convergent regimes; Δk: Reduced number of regimes

479 after accounting for climatic niche convergence; c: number of shifts that are towards

480 convergent regimes occupied by multiple lineages; k' conv: Number of convergent regimes

481 reached by multiple shifts. Selected best model in bold.

482

Regime	AICc	Δ AICc	k'	Δk	c	k' conv
1	2502	104	29	0	0	0
2	2493	95	28	1	2	1
3	2485	87	27	2	4	2
4	2477	79	26	3	6	3
5	2469	71	25	4	7	3
6	2461	63	24	5	9	4
7	2453	55	23	6	11	5
8	2446	48	22	7	13	6
9	2439	41	21	8	15	7
10	2432	34	20	9	16	7
11	2426	28	19	10	17	7
12	2421	23	18	11	19	8
13	2416	18	17	12	21	9
14	2411	13	16	13	22	9
15	2407	9	15	14	24	10
16	2402	4	14	15	24	9
17	2400	2	13	16	25	9
18	2398	1	12	17	26	9
19	**2398**	**0**	**11**	**18**	**27**	**9**

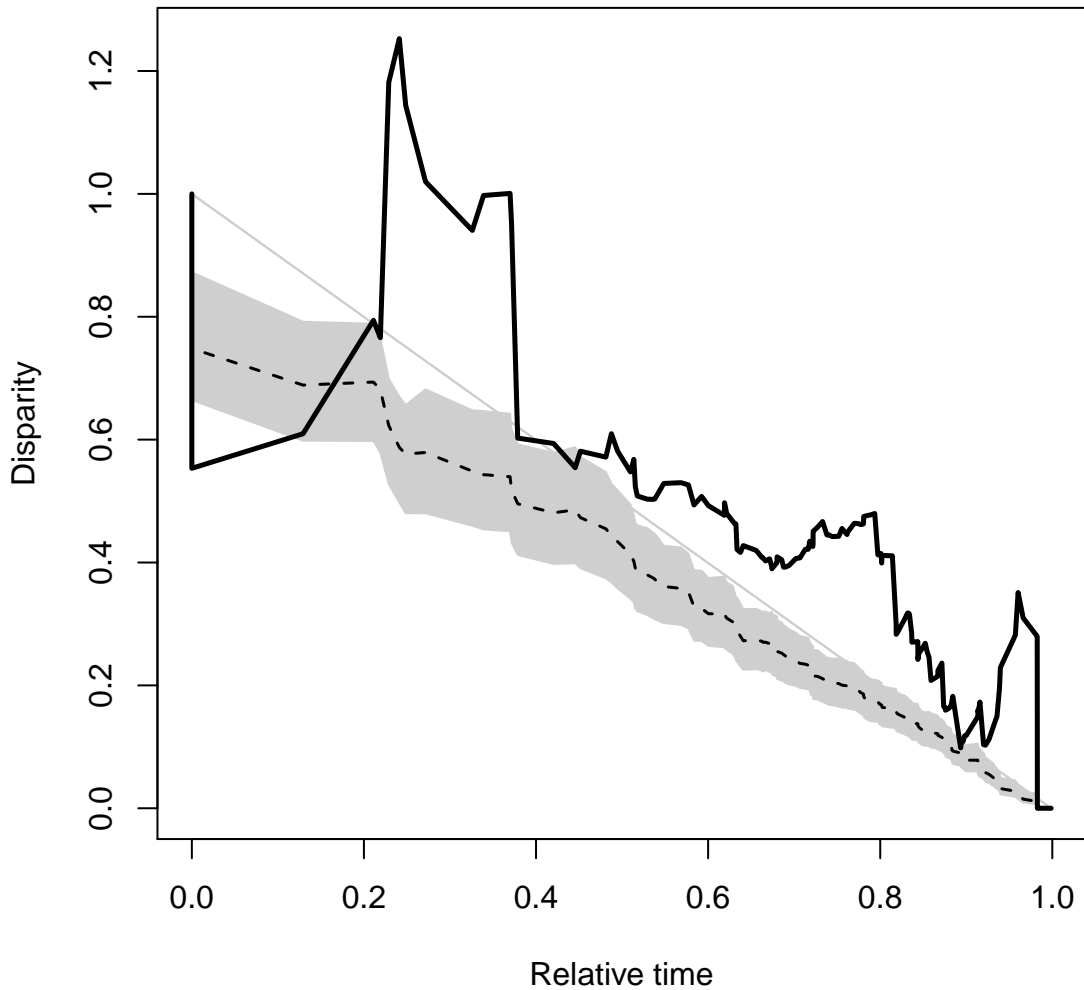483

484

485 **FIGURE LEGENDS**

486 Figure 1. Convergent evolution of climatic niche in the Caribbean *Anolis* lizards. a) Calibrated

487 phylogeny for Caribbean *Anolis* lizards with climatic niche data and adaptive regimes

488 identified using a SURFACE approach. Colored branches represent convergent adaptive peaks

489 (or climate regimes) and gray or black branches represent non-convergent regimes. b)

490 Climatic space occupied by the Caribbean *Anolis* species. Large colored dots represent the

491 same convergent adaptive regimes identified in the phylogeny and small colored dots

492 represent the species that have evolved around these adaptive optima. Large gray or black dots

493 represent the same non-convergent regimes identified in the phylogeny. Small gray or black

494 dots correspond to species that have evolved toward these regimes.

495

496 Figure 2. Disparity through time plots (DTT) for temperature and precipitation for the

497 Caribbean *Anolis* lizards. Relative time indicates the entire time span of the phylogeny from 0

498 (i.e., root) to 1 (i.e., tips). The dashed line indicates the median DTT based on 1000

499 simulations of each trait under a Brownian motion model. The gray shaded area indicates the

500 95% DTT range for the simulated data.

501

502 Figure 3. Boxplots of climatic niche structure (Ecological distances), multivariate

503 environmental similarity surface (MESS) and climatic suitability (Maxent's logistic outputs)

504 between native (occupied) islands and target (non-occupied) islands. See main text for details.

luciae
bonairensis
griseus
trinitatis
richardi
aeneus
extremus
roquet
occultus
bartschi
vermiculatus
equestris
luteogularis
baracoae
smallwoodi
noblei
chlorocyanus
coelestinus
singularis
aliniger
darlingtoni
monticola
koopmani
bahorucoensis
henderson
dolichocephalus
barbouri
etheridgei
insolitus
fowleri
olssoni
alumina
semilineatus
cuvieri
christophei
eugenegrahami
ricordii
barahonae
baleatus
barbatus
guamuhaha
chamaeleonides
aliceroi
porcus
argenteolus
lucius
altitaceus
inexpectatus
alfaroi
macilentus
vanidicus
clivicola
reyesi
cupeyalensis
cyanopleurus
alayoni
paternus
acoustiraps
pitanus
sheplani
garridoi
guazuma
loysianus
pumilus
centralis
argillaceus
isolepis
altitudinalis
oporinus
porcatus
smaragdinus
longiceps
maynardi
allisoni
brunneus
marcanoi
strahmi
longitibialis
whitemani
breslini
haetianus
cybotes
armouri
shrevei
valencienni
lineatopus
reconditus
opalinus
darani
grahami
conspersus
aliogus
imias
ahli
rubribarbus
jubar
confusus
homolechis
quadriocellifer
ophiolepis
sagrei
bremeri
mestrei
lugubris
schwartzi
watsi
leachii
bimaculatus
gingivinus
oculatus
ferreus
lividus
nubilus
sabanus
marmoratus
wattsi
brevirostris
caudalis
marron
favillarum
aurifer
vinosus
dominicensis
properus
gingularis
distichus
ravitergum
stratulus
acutus
evermanni
krugi
pulchellus
poncensis
gundlachi
cooki
monensis
scriptus
ernestwilliamsi
cristatellus
desechensis