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1 **Geographic range did not confer resilience to extinction in**
2 **terrestrial vertebrates at the end-Triassic crisis**

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7

8 **Rates of extinction vary greatly through geological time, with losses particularly**
9 **concentrated in mass extinctions. Species duration at other times varies greatly, but the**
10 **reasons for this are unclear. Geographical range correlates with lineage duration**
11 **amongst marine invertebrates, but it is less clear how far this generality extends to other**
12 **groups in other habitats. It is also unclear whether a wide geographical distribution**
13 **makes groups more likely to survive mass extinctions. Here, we test for extinction**
14 **selectivity amongst terrestrial vertebrates across the end-Triassic event. We**
15 **demonstrate that terrestrial vertebrate clades with larger geographical ranges were**
16 **more resilient to extinction than those with smaller ranges throughout the Triassic and**
17 **Jurassic. However, this relationship weakened with increasing proximity to the end-**
18 **Triassic mass extinction, breaking down altogether across the event itself. We**
19 **demonstrate that these findings are not a function of sampling biases; a perennial issue**
20 **in studies of this kind.**

21

22 Is it possible to make generalisations about which clades and higher taxa are most likely to go
23 extinct on geological timescales? Geographic range is often claimed to be a determinant of
24 extinction vulnerability¹⁻⁶. Groups with restricted ranges are widely believed to suffer
25 extinction more frequently than those with broader ranges¹ because the latter are thought to

26 be afforded some resilience to regional environmental perturbations^{7,8}. During global biotic
27 crises, by contrast, there is reasoned to be no such selectivity^{2,6} since widespread
28 environmental disturbances simultaneously affect both wide and narrow ranging taxa on
29 global scales^{1,3,6}. Surprisingly, the effect of geographic range on extinction risk has not been
30 tested comprehensively for the terrestrial fossil record, with a striking paucity of studies on
31 vertebrates of any kind. Most published studies focus on marine invertebrates^{3-6,8-10}, and
32 despite geographic range being used as a major criterion for assessing the extinction risk of
33 modern terrestrial species¹¹, it is unclear that the findings from these fossil taxa can be
34 extended to all groups in all major habitats. Moreover, little is known about the difference
35 between intervals with background levels of extinction and those characterised as mass
36 extinctions³. The only way to answer such questions is to utilise fossil evidence of past
37 organismal distributions^{5,12}.

38 The Triassic to Jurassic is a critically important period in terrestrial vertebrate
39 evolution^{13,14}. In particular, it follows the largest of all mass extinctions, the Permo-Triassic
40 (P/T) ‘great dying’¹³⁻¹⁵. Many terrestrial vertebrate lineages originated in the aftermath of the
41 P/T event, but were subsequently subjected to major changes in terrestrial ecosystems
42 throughout the ensuing Triassic and Jurassic. These changes included the gradual aridification
43 of Pangaea¹⁶, as well as its initial rifting and fragmentation¹⁷ allied to the eruption of the
44 Central Atlantic Magmatic Province (CAMP)^{18,19}. This culminated in the end-Triassic mass
45 extinction event^{16,20}, which saw the demise of numerous amphibian and reptile groups prior
46 to the subsequent rise to dominance of the dinosaurs^{13,16,21-23}.

47 The significant vertebrate faunal turnover throughout the Triassic and Jurassic (lying
48 either side of the end Triassic mass extinction) make this an ideal period in which to study
49 extinction selectivity. We therefore collated palaeobiogeographical and stratigraphic
50 distributional data²⁴ for Triassic and Jurassic terrestrial vertebrate clades in order to ask three

51 questions. 1. Is there is a relationship between palaeobiogeographical distribution and the risk
52 of extinction during ‘normal’ times? 2. Does any such relationship disappear across the end-
53 Triassic mass extinction? 3. Can any of these findings be attributed to sampling biases?

54 We find that wider geographical range conferred greater resilience to extinction in
55 terrestrial vertebrate groups throughout most of the Triassic and Jurassic. However, this
56 insurance weakened towards the end-Triassic mass extinction, and was imperceptible across
57 the event itself. Major sampling biases were discounted as the cause of these patterns.

58

59 **Results and Discussion**

60 **Geographic range and diversification rates are correlated.** Diversification rates and
61 changes in geographic range at the clade level are positively and strongly correlated across all
62 time bins (Figs. 1 and 2 and Supplementary Table 1), with weaker (but still mostly
63 significant) correlations when the data are subdivided into Epochs (Fig. 2 and Supplementary
64 Table 1). The strong correlation between changes in geographic range and diversification rate
65 across all time intervals (and at Epoch level and within stage-level time bins) confirms that
66 increasing range size coincides with increasing diversity, whilst range size reductions
67 typically attend diversity reductions. Taxa with larger geographic ranges are therefore more
68 likely to exhibit increasing diversity and lower extinction rates than those with smaller
69 ranges. Greater rates of origination might also be expected to result from more extensive
70 ranges; firstly because large ranges are more likely to be fragmented into peripheral isolates,
71 secondly because larger ranges encompass a greater diversity of environments and selective
72 forces^{25,26}. This pattern is the opposite of that proposed for the marine invertebrate fauna,
73 where taxa with narrow ranges show higher origination rates^{6,27}. The results from our
74 geographic range data sets, both raw convex hull and standardized mean great circle distances

75 (Fig. 1), are similar, demonstrating that our findings are not contingent upon the precise
76 methodology used.

77

78 **This relationship breaks down across the mass extinction.** Strikingly, rates of geographic
79 range change and diversification are not significantly correlated immediately before the end-
80 Triassic extinction (during the Rhaetian), whereas this correlation is significant even in the
81 Carnian and Norian stages that immediately precede it (Fig. 2 and Supplementary Table 1).
82 Hence, diversification rate becomes decoupled from range size change rate across the
83 extinction boundary and the insurance against extinction offered by larger geographic ranges
84 at other times disappears. During the end-Triassic mass extinction event, relatively
85 widespread groups are as likely to suffer high levels of extinction as groups with narrower
86 geographic ranges. For example, Phytosauria and Theropoda have similar, geographic ranges
87 in the Rhaetian (Fig. 3). However, phytosaurs suffer complete extinction at the end-Triassic,
88 whereas theropod diversity remains stable across the boundary and into the Hettangian, even
89 whilst undergoing significant range expansion (Fig. 3). Of the time intervals that do not show
90 significant correlation between diversification rate and geographic range change rate, all have
91 very small sample sizes apart from the Rhaetian. The standardised mean great circle distance
92 (GCD) range metrics show less correlation with diversification rate than the raw convex hull
93 metric (Supplementary Table 1). This is unsurprising since a reduced sample size leads to a
94 reduction in statistical power. However, many of these non-significant correlations still have
95 relatively high correlation coefficients and are approaching significance, whereas the
96 Rhaetian results are clearly different (with negative coefficients that are far from significant)
97 (Supplementary Table 1). Our temporal divisions are very much longer (2.0 to 18.9
98 Myrs)^{28,29} than the extinction event²⁰, which occurred in pulses over a period of less than 1.0
99 Myr¹⁹. Effects are therefore time averaged, meaning that the breakdown of the relationship

100 between diversification rate and the rate of geographic range change in the very end Triassic
101 (an interval known to contain a major biotic crisis) is even more striking.

102

103 **Sampling biases have little effect on our results.** We observed several significant bivariate
104 correlations between diversification rate, geographic range change rate and various putative
105 sampling proxies detrended using first differences (Supplementary Tables 2-3). However,
106 multiple regression models identified the changes in geographic range rate as the dominant
107 variable influencing diversification rate (Table 1 and Supplementary Tables 4-9).

108 Although certain parts of the Triassic-Jurassic are reputed to have a poor terrestrial
109 fossil record (i.e. Ladinian, Toarcian-Mid Jurassic)^{13,20,30-32}, the Late Triassic possesses one of
110 the best^{23,32} (Fig. 4). We see positive correlations between land area and geographic range and
111 a negative correlation between sea level and range in the GCD data, but also positive
112 correlations between sea level and geographic range and between sea level and diversification
113 rate in the convex hull data. This suggests that greater land area and lower sea levels may
114 result in greater geographic ranges amongst terrestrial organisms. However, the negative
115 correlation between standardised range and sea level (and the lack of correlation between
116 diversification rate and land area) suggests that while expanding landmasses might be
117 expected to induce the expansion of terrestrial ranges and increase diversification, climatic
118 and other effects complicate this relationship. Indeed, the typically harsh environments in
119 deep continental interiors may constrain many ranges. Specifically, lethally hot temperatures,
120 particularly in the Early Triassic, may have limited or even excluded diversity in equatorial
121 regions³³. Individual lineage ranges correlate with total ranges across time bins, and both
122 appear to reflect the same underlying pattern. The considerable variation between individual
123 lineage ranges within each bin (coupled with the fact that the standardised range metrics still
124 show some correlation with total range, albeit weaker than the raw range metrics) indicates

125 that range estimates are not governed straightforwardly by sampling intensity (Figs. 1 and 3).
126 Moreover, the absence of terrestrial vertebrates from equatorial regions is entirely plausible
127 during the climatic greenhouse of the Early Triassic³³. Groups with broader geographical
128 distributions are likely to be subject to a wider range of selective pressures and the peripheral
129 isolation of sub groups; both factors favouring speciation and increasing diversity^{25,26}.
130 However, the weak correlation observed between changes in fossil abundance and both
131 diversification rate and geographic range change may be representative of sampling bias. It is
132 also possible that a greater investment of research effort in more abundant fossil groups may
133 have resulted in increased taxonomic splitting³⁴.

134 We also observed significant pairwise correlations between both raw and
135 standardised geographic range change and diversification rate on one hand, and changes in
136 numbers of formations on the other. Although formation counts are regarded as effective
137 sampling proxies for terrestrial data sets³⁵, redundancy between sampling proxies and
138 diversity metrics (arising from the probable non-independence of formation and fossil
139 content) remains problematic³⁶⁻³⁸. In practice, the level of this redundancy is likely to be
140 minimised by the use of all terrestrial vertebrate-bearing formations^{39,40}, rather than by
141 adopting a stricter count of only those formations containing a particular group of terrestrial
142 vertebrate fossils^{31,41-43}. However, standardisation of geographic range data results in the
143 removal of significant correlations between range size and fossil abundance, coupled with a
144 weakening of the correlation between range size and total range size (i.e. standardising
145 geographic range calculations to a constant sample size across all lineages in each time bin
146 appears to remove putative sampling effects). By contrast, standardising range data does not
147 affect the correlation between range size and formation counts. This last relationship may
148 therefore arise from redundancy³⁶, rather than being a temporal bias resulting from variation

149 in the amount of preserved sedimentary rock (and concomitant intensity of sampling) through
150 geological time.

151 The multiple regression models show that geographic range change is the dominant
152 driver of diversification rate through the Triassic-Jurassic, to the exclusion of all the sampling
153 proxies in the model using convex hulls, but with total range and sea level showing some
154 influence in the standardised mean great circle distance models. This suggests that, although
155 sampling biases are a perennial issue in fossil data sets, the link between changes in
156 geographic range and diversification rate appear robust, despite the patchy nature of the
157 vertebrate fossil record.

158

159 **Implications for extinction studies.** We demonstrate that broad geographic range conferred
160 insurance against extinction on major clades of terrestrial vertebrates during periods with
161 background levels of extinction. In line with marine invertebrate studies across the same
162 biotic crisis⁶ and at other times in the Phanerozoic³, this insurance disappeared during the
163 end-Triassic mass extinction. However, these results are in marked contrast to patterns
164 reported for marine invertebrates at the Cretaceous-Paleogene extinction^{9,44} (where groups
165 with larger geographic ranges retain increased resilience to extinction across the crisis than
166 those with smaller ranges). It is reasonably common to observe discrete macroevolutionary
167 patterns in different higher taxa or across different major habitats. Notable examples include
168 the incongruence between terrestrial and marine Phanerozoic diversity curves⁴⁵⁻⁴⁷, variations
169 in the apparent force of Cope's rule *sensu lato* in different higher taxa⁴⁸⁻⁵⁰, and variations in
170 the relationships between body size, population density and fecundity across clades^{51,52}.
171 However, the differences between patterns observed at major extinction events may result
172 from differences between the particular driving forces of the crises themselves. These
173 differences highlight the need for greater numbers of large-scale, comparative studies before

174 attempting to make macroevolutionary generalisations. Fortunately, the expansion and
175 refinement of resources such as the Paleobiology Database, coupled with quantitative tools
176 such as GIS, have great potential for testing temporal and spatial macroevolutionary patterns.
177 Equally, palaeontological data provides a broader perspective on the current biodiversity
178 crisis. Specifically, it enables deep time tests of the purported relationships between present
179 day extinction susceptibility and geographical range size^{53,54}, latitudinal distribution⁵⁵, niche
180 breadth⁵⁶ and body size^{57,58}.

181

182 **Methods**

183 **Fossil occurrence data.** Stage level occurrence data for Triassic-Jurassic terrestrial
184 vertebrates were initially downloaded from the Paleobiology Database²⁴
185 (<https://paleobiodb.org>) on 4th February, 2013 (last accessed 20th April, 2015) and, after pre-
186 processing, consisted of 3507 occurrences of 857 genera (see Supplementary Note 1 for
187 Paleobiology Database download specifications). Terrestrial vertebrate occurrences from
188 marine deposits were not included as they would not give a true representation of geographic
189 range. Ichnogenera and other form taxa were then removed from the data set as they could
190 not be assigned accurately to parent genera. Marine tetrapod taxa recorded in terrestrial
191 formations were also removed. Generic indeterminate taxa and taxa with uncertain generic
192 assignments (i.e. *aff.*, *cf.*, *ex gr.*, *sensu lato*, ?) were also excluded. Although these exclusions
193 inevitably resulted in an underestimation of the geographic range of higher taxonomic
194 groups, it would be inappropriate to compare ranges constructed from taxa of uncertain
195 affiliation with rates of generic extinction, origination, and diversification, which cannot
196 include these indeterminate occurrences.

197 Fossil occurrences were vetted for synonymy and outdated taxonomy and sorted into
198 higher taxonomic groups according to phylogenetic and ecological relationships within the

199 constraints of reasonable sample sizes (see Supplementary Note 1 for detailed classification
200 of taxa). As with all higher taxonomic classification, groups were not directly comparable.
201 This is an unavoidable problem unless working at the species or, to a lesser extent, the
202 generic level. Two datasets were compiled: data₁ and data₂ (Supplementary Fig. 1). Data₁
203 (Supplementary Data 1) contained a number of paraphyletic assemblages where basal taxa of
204 particular lineages were grouped together to form a paraphyletic ‘stem’ assemblage (e.g.
205 Archosauriformes, basal Cynodontia, Dinosauromorpha) (Supplementary Fig. 1). Since the
206 inclusion of paraphyletic groups is arguably problematic (they do not represent ‘true’
207 evolutionary groups), a second dataset excluding all parapyta was also prepared. In data₂, the
208 paraphyletic assemblages were collapsed into smaller, monophyletic family-level groups
209 wherever possible (Supplementary Fig. 1). The two data sets correlated very closely in terms
210 of both geographic range change rate and diversification rate. All analyses in the manuscript
211 therefore refer exclusively to data₁.

212 Fossil occurrences were binned at the stratigraphic stage level. Any occurrences not
213 assigned to a stage were attached to the stage, or range of stages, corresponding to the
214 formation from which they were recovered. Fossil occurrences that were assigned to more
215 than one stage were randomly assigned to a single stage within their given range, a process
216 that was repeated 1,000 times to obtain a mean value. This method avoided either the
217 artificial inflation or deflation of taxonomic richness in any given stage compared to
218 maximum or minimum diversity values.

219

220 **Sampling and environmental proxy data.** *Non-marine area*⁵⁹: A mean estimate of the
221 continental landmass for each Stage. It was anticipated that geographic range would correlate
222 positively with land area as the area of terrestrial habitat creates an upper limit for the
223 geographic range of terrestrial organisms. These measurements were derived from an

224 independent source⁵⁹, and were subject to different definitions of Stage-level boundaries than
225 the fossil occurrence data set, which used the Geological Time Scale 2012⁶⁰.

226 *Sea level*⁶¹: A mean estimate of relative sea level for each Stage. It was expected that
227 geographic range would correlate inversely with mean sea level, as higher sea level would
228 result in less terrestrial landmass for terrestrial organisms to inhabit. As with the non-marine
229 area measurements, the sea level averages were obtained from an independent source⁶¹ and
230 are subject to different definitions of Stage-level boundaries from the fossil occurrence data
231 set⁶⁰.

232 *Terrestrial formations*²⁴: Formation counts are widely regarded as effective sampling proxies
233 for the terrestrial fossil record^{31,35,42,62}. It is still unclear if this is true, as formation counts
234 probably share a common signal with fossil occurrence data (i.e. formations are not
235 independent from their fossil content^{36,37}). However, given the lack of comprehensive data on
236 global sedimentary rock outcrop area, formation counts offer the only possible metric of
237 global rock availability. In this analysis, redundancy was minimised by using a total count of
238 terrestrial tetrapod bearing formations, rather than a strict count of group-specific bearing
239 formations. There is also an argument for redundancy between formation counts and
240 geographic range, as a taxon that is genuinely wide ranging is more likely to be present in
241 more formations across the globe than a taxon with a small geographic range. Such
242 possibilities were explored using multiple regression models.

243 *Fossil abundance*²⁴: Fossil abundance per time period serves as a proxy for human sampling
244 and collecting effort. However, there is danger of circularity, as palaeontologists will be more
245 likely to collect from formations yielding a higher number of fossils^{38,63}. Therefore, fossil
246 abundance may be more representative of preservational factors or true biological abundance,
247 rather than a measure of human sampling effort.

248 *Total geographic range*: It is reasonable to assume that vertebrates were not genuinely absent
249 from large areas of the globe through parts of the Triassic-Jurassic. Therefore, if total
250 geographic range (i.e. the total geographic range of all tetrapod occurrences per time bin)
251 were to correlate strongly with the geographic ranges of individual fossil groups, it would
252 indicate that the pattern of geographic range through the study period is controlled by spatial
253 sampling rather than reflecting a biological pattern.

254

255 **Analysis.** Palaeogeographic ranges were constructed by converting modern fossil occurrence
256 coordinates to palaeocoordinates using *PointTracker*⁶⁴. Palaeogeographic ranges were
257 constructed using two methods: (i) in *ArcGIS v10.1* using convex hulls around the
258 palaeogeographic occurrences for each group^{65,66}; and (ii) using mean great circle distances
259 (GCD) between palaeogeographic occurrences with sample sizes standardised to 5 and 10
260 occurrences per lineage per time bin and replicated 1,000 times to obtain a mean value. GCD
261 distances were calculated using the spherical law of cosines (as an acceptable approximation
262 of the Haversine formula for terrestrial calculations.

263 Per lineage origination (O_r) and extinction (E_r) rates were calculated using the
264 methodology of Foote⁶⁷ and modified by Foote⁶⁸:

265 (1) $O_r = -\ln \frac{N_{bt}}{N_{ft} + N_{bt}}$

266 (2) $E_r = -\ln \frac{N_{bt}}{N_{bL} + N_{bt}}$

267 Where N_{bt} = number of range-through taxa, N_{ft} = number of taxa that originate within time
268 bin and cross top boundary of time bin, N_{bL} = number of taxa that cross bottom boundary of
269 time bin but make their last appearance in time bin. Rates were not expressed relative to time
270 bin duration; although this may cause underestimation of rates in shorter time bins relative to

271 longer time bins, Foote⁶⁹ demonstrated that both extinction and origination are pulsed rather
272 than spread throughout time intervals. All analyses were carried out at the generic level.

273 No significant correlations were detected between geographic range change and
274 extinction rate or between geographic range change and origination rate (Supplementary
275 Table 10). The absence of significant correlations between origination/extinction rates and
276 change in geographic range could be regarded as somewhat surprising, but this result is a
277 function of the paucity of data for the rate calculations. However, the extinction and
278 origination rate calculations rely on taxa that range-through three consecutive time bins⁶⁷,
279 which are scarce in this data set because of the patchiness of the terrestrial fossil record and
280 the long durations of the time bins. Therefore, it was judged that a metric of diversification
281 calculated from generic range data offered a more robust picture of biotic change.
282 Diversification rate (D_r) and geographic change rate (R_r) were calculated using a metric
283 modified from Rode and Lieberman⁷⁰:

284
$$(3) \quad D_r = (\ln D_1 - \ln D_0)$$

285
$$(4) \quad R_r = (\ln R_1 - \ln R_0)$$

286 where D_1 = ranged-through diversity calculated from first and last appearances for current
287 time interval, D_0 = ranged-through diversity calculated from first and last appearances for the
288 previous time interval, R_1 = geographic range in time interval, R_0 = geographic range in
289 previous time interval.

290 Relationships between geographic range change and generic diversification rates
291 within clades were tested using pairwise Spearman's rank-order correlation tests. Putative
292 sampling biases were investigated using both pairwise correlation and multiple regression
293 models, with diversification rate as the dependent variable and geographic range and various
294 sampling proxies as independent variables. First differencing was used to detrend the

295 sampling proxy data prior to comparison with the biotic rate data. All statistical analyses
296 were carried out in R 3.1.1.

297

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481

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489

490 **Author Contributions**

491 A.M.D. designed the project and compiled the data. M.A.W. wrote scripts. A.M.D. and
492 M.A.W. analysed the data and wrote the manuscript.

493

494 **Additional Information**

495 **Supplementary Information** accompanies this paper at

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497

498 **Competing financial interests:** The authors declare no competing financial interests.

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501 **Figure Legends**

502

503 **Figure 1| Mean rates of change in geographic range size and diversification rates for**
504 **terrestrial vertebrates, partitioned by time bin.** Rate of change in geographic range size
505 (Δ Geographic range) as represented by (a) convex hulls around raw palaeogeographic
506 occurrences and (b) mean great circle distance (GCD) between palaeogeographic
507 occurrences standardised to 5 and 10 samples; and (c) mean vertebrate diversification rates
508 of ranged-through diversity data (Δ Diversification). The fossil records of the Ladinian¹²,
509 Toarcian¹⁹, and much of the Middle Jurassic²⁸⁻³⁰, are of lower quality than the rest of
510 Mesozoic, and this may contribute to some of the negative diversity changes therein. The
511 drop in diversity observed through the Rhaetian could also be regarded as a sampling
512 artefact as the Rhaetian is not as well sampled as the preceding Norian. However, the upper
513 Triassic represents one of the highest quality terrestrial fossil records^{22,30}. Alternating grey
514 and white bars correspond to Triassic-Jurassic epochs..

515

516 **Figure 2| Scatter plots of diversification rates against per lineage rates of change in**
517 **geographic range size.** (a-c) Rate of geographic range size change (Δ Geographic range)
518 as calculated using convex hulls around raw occurrence data for (a) all time bins; (b) Late
519 Triassic; (c) Rhaetian. (d-f) Rate of geographic range size change calculated as mean great
520 circle distances between occurrences standardised to samples of 5 and 10 occurrences for
521 (d) all time bins; (e) Late Triassic; and (f) Rhaetian. Spearman rank correlation coefficients
522 *significant at $p < 0.05$, **significant at $p < 0.01$, ***significant at $p < 0.001$..

523

524 **Figure 3| Geographic range maps before and after the end-Triassic mass extinction.**
525 Convex hull geographic range maps and mean generic diversity of six terrestrial vertebrate
526 groups during the (a) Rhaetian and (b) Hettangian. The Aetosauria, Cynognathia and
527 Phytosauria became extinct during the biotic crisis, despite the widespread distribution of

528 Cynognathia and Phytosauria in the Rhaetian. The Probainognathia, Sauropodomorpha and
529 Theropoda all survived the biotic crisis and expanded their ranges in the Hettangian, albeit
530 with different diversification trajectories. The diversity of Sauropodomorpha increased, the
531 diversity of Theropoda was stationary, and that of Probainognathia decreased across the
532 boundary.

533

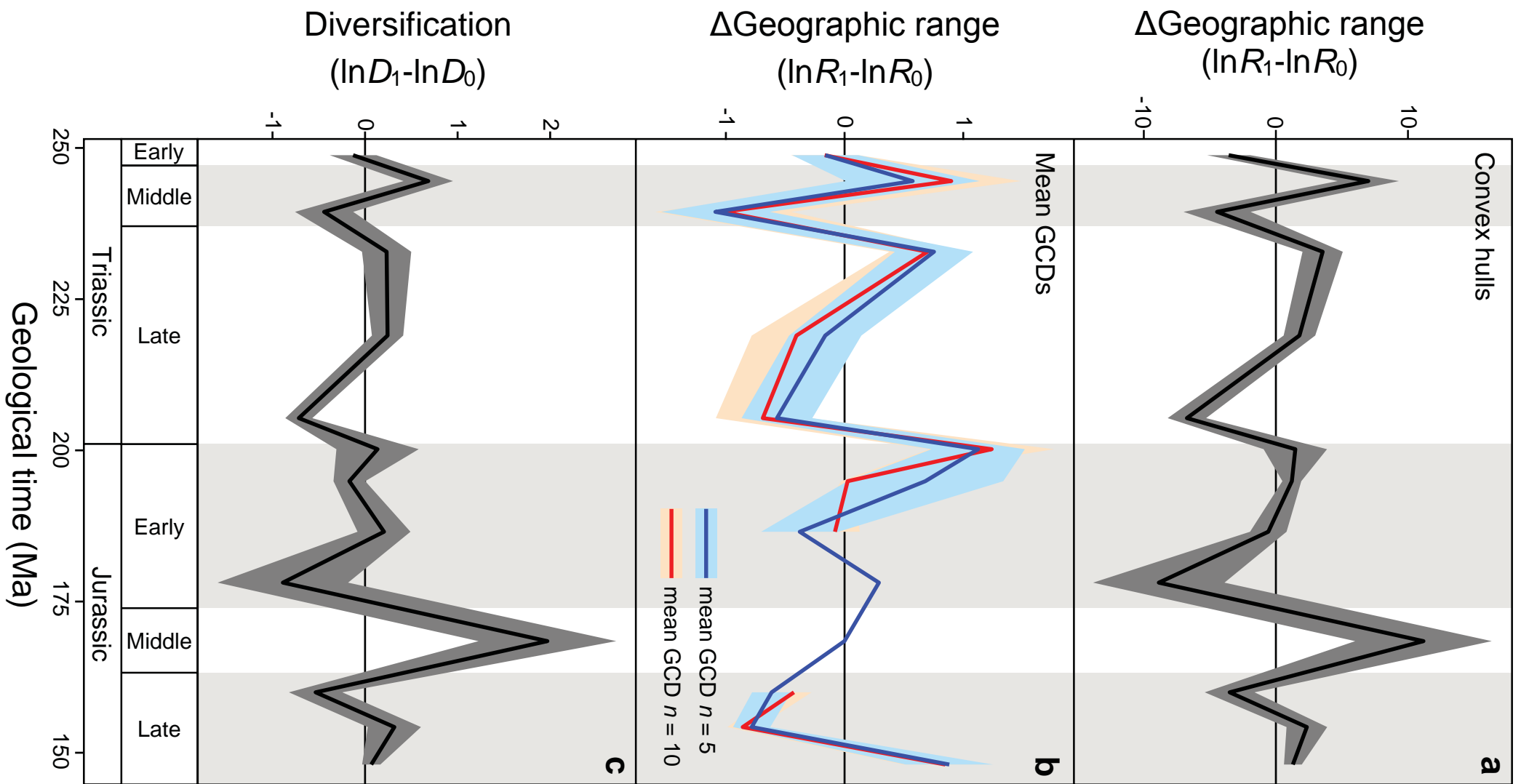
534 **Figure 4| Sampling and environmental proxy data.** (a) non-marine area⁵⁸; (b) average
535 sea level⁶⁰; (c) terrestrial formation count²⁴; (d) fossil abundance²⁴; (e) total geographic
536 range of all taxa. Alternating grey and white bars correspond to Triassic-Jurassic epochs.

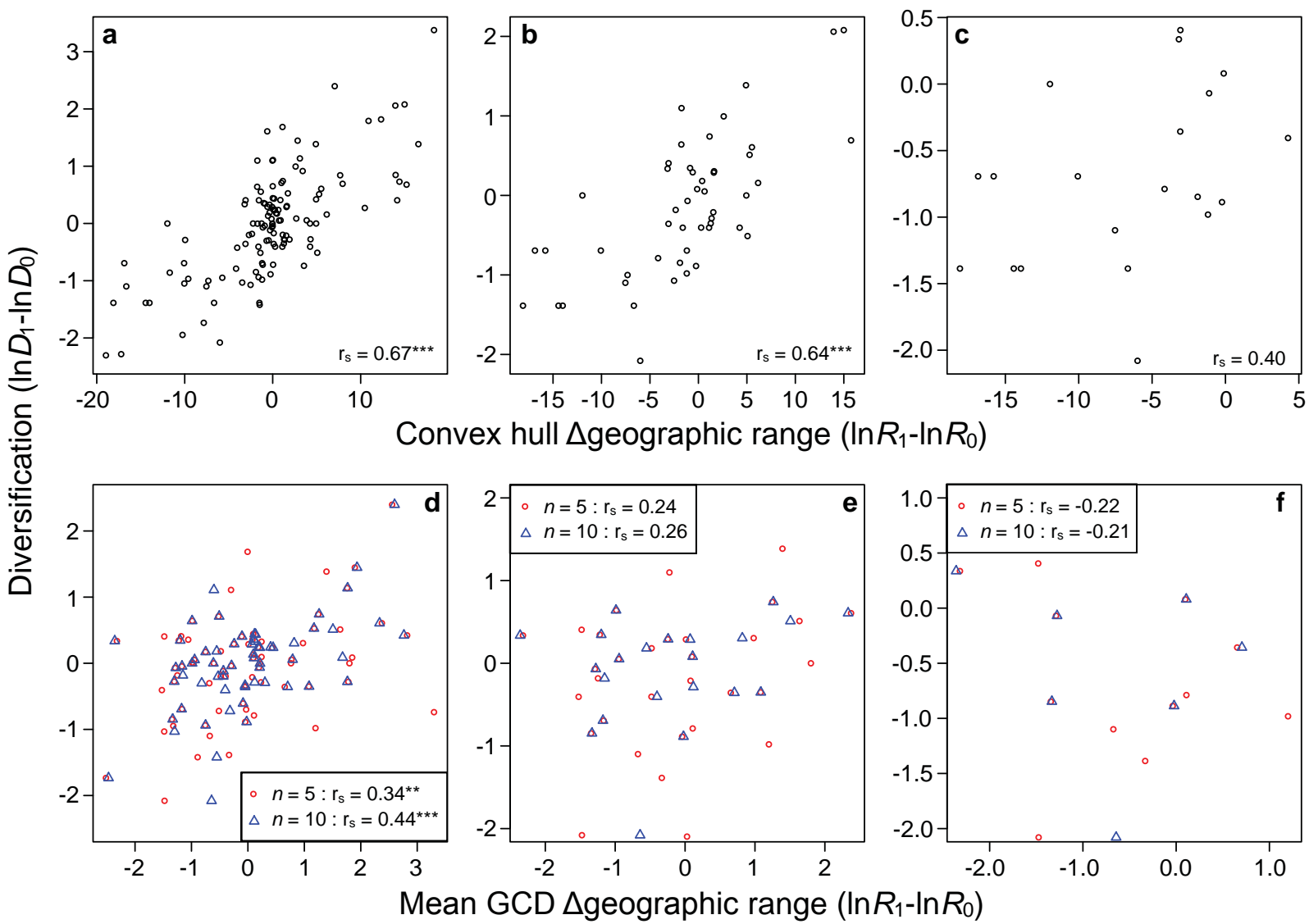
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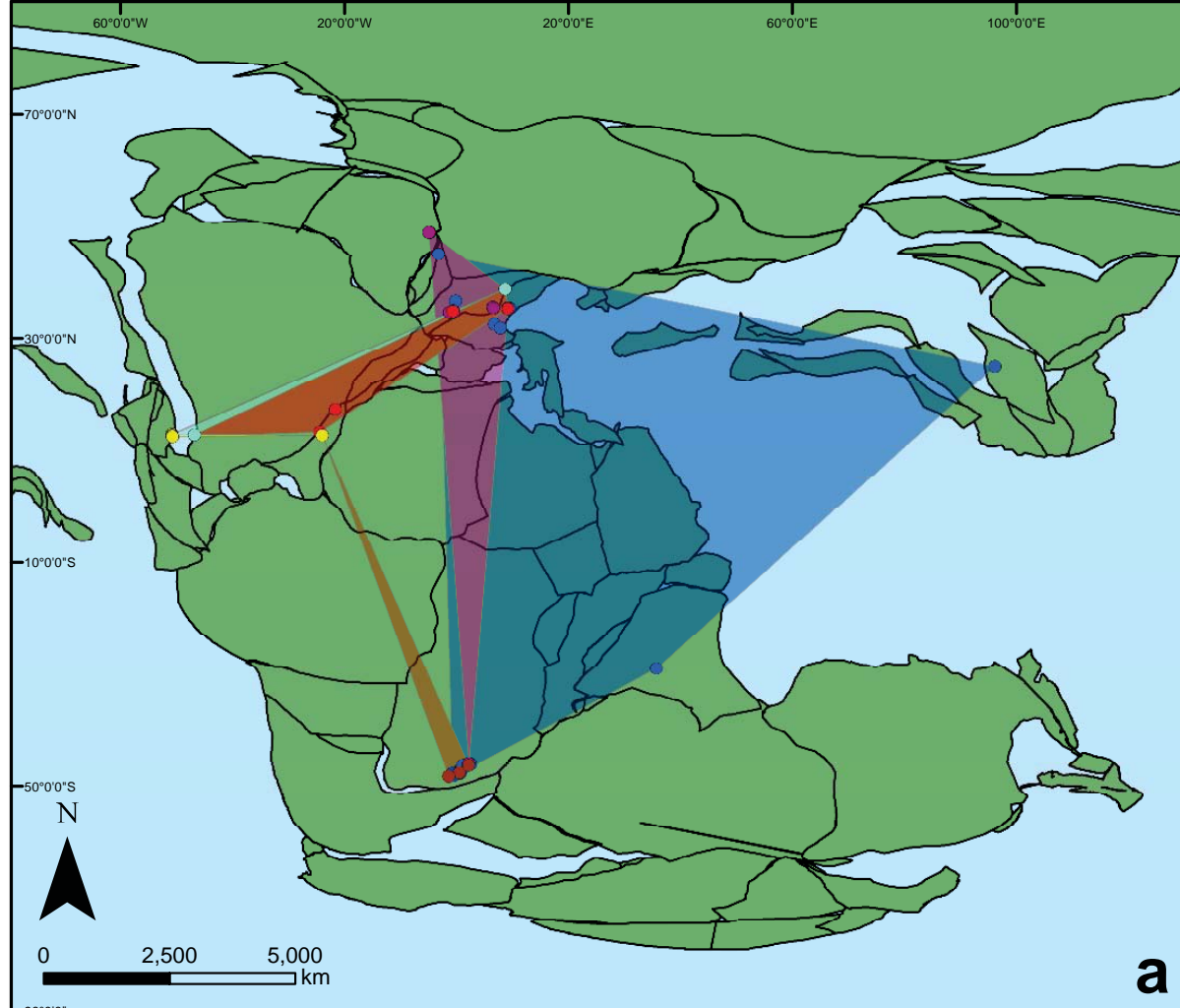
Table 1| Summary of multiple regression models of diversity change (dependent variable) in terms of geographic range change and sampling and environmental proxies.







Model	Dependent	Independents	adj R ²	p	AIC
Convex full	Diversity change	Range change + land area + sea level + formations + abundance + total range	0.53	< 0.001	-98.59
Convex best	Diversity change	Range change	0.64	< 0.001	-100.53
GCD5 full	Diversity change	Range change + land area + sea level + formations + abundance + total range	0.22	< 0.001	-65.5
GCD5 best	Diversity change	Range change + total range + sea level	0.23	< 0.001	-68.95
GCD10 full	Diversity change	Range change + land area + sea level + formations + abundance + total range	0.32	< 0.001	-63.66
GCD10 best	Diversity change	Range change + total range + sea level	0.35	< 0.001	-68.97

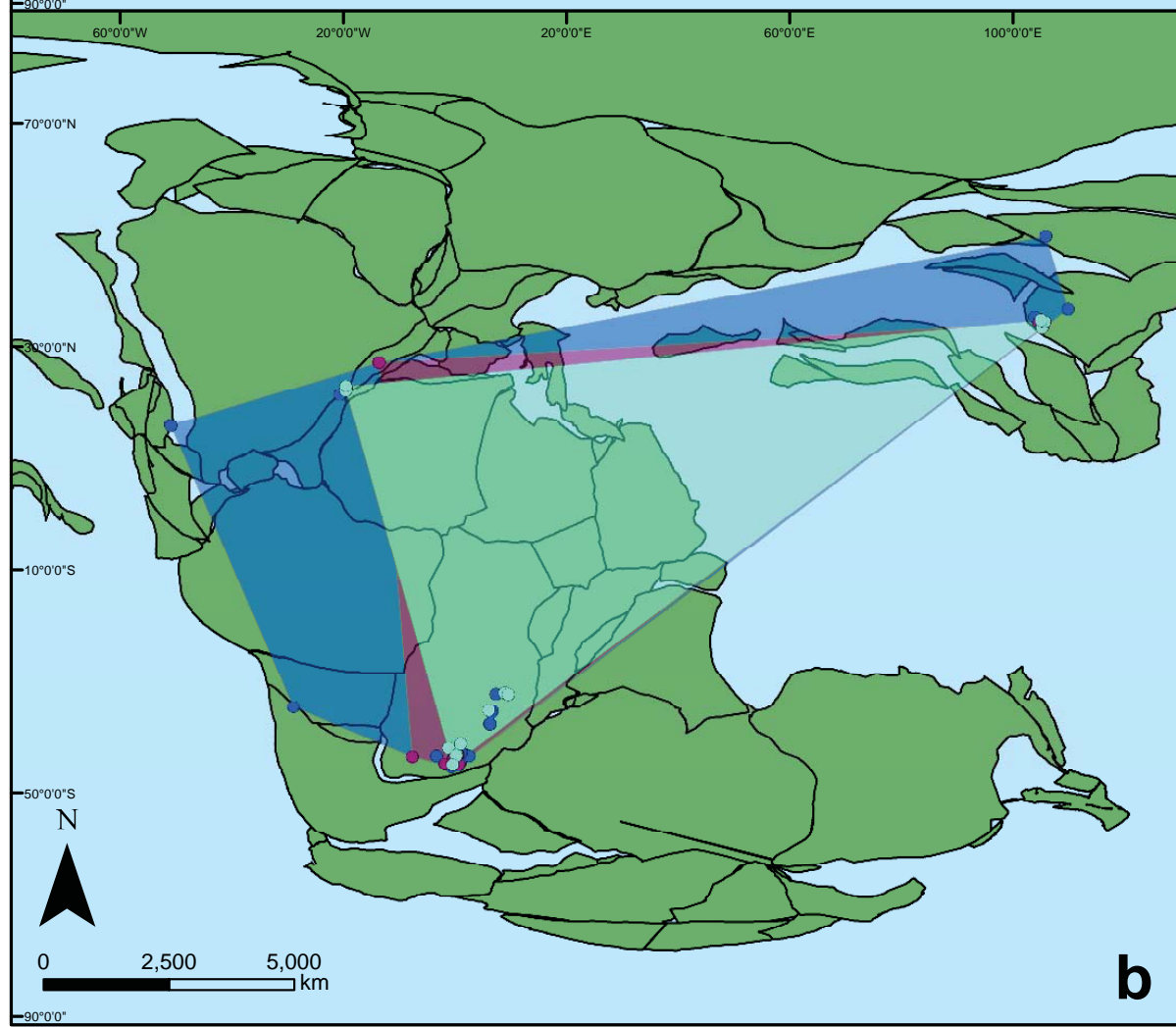
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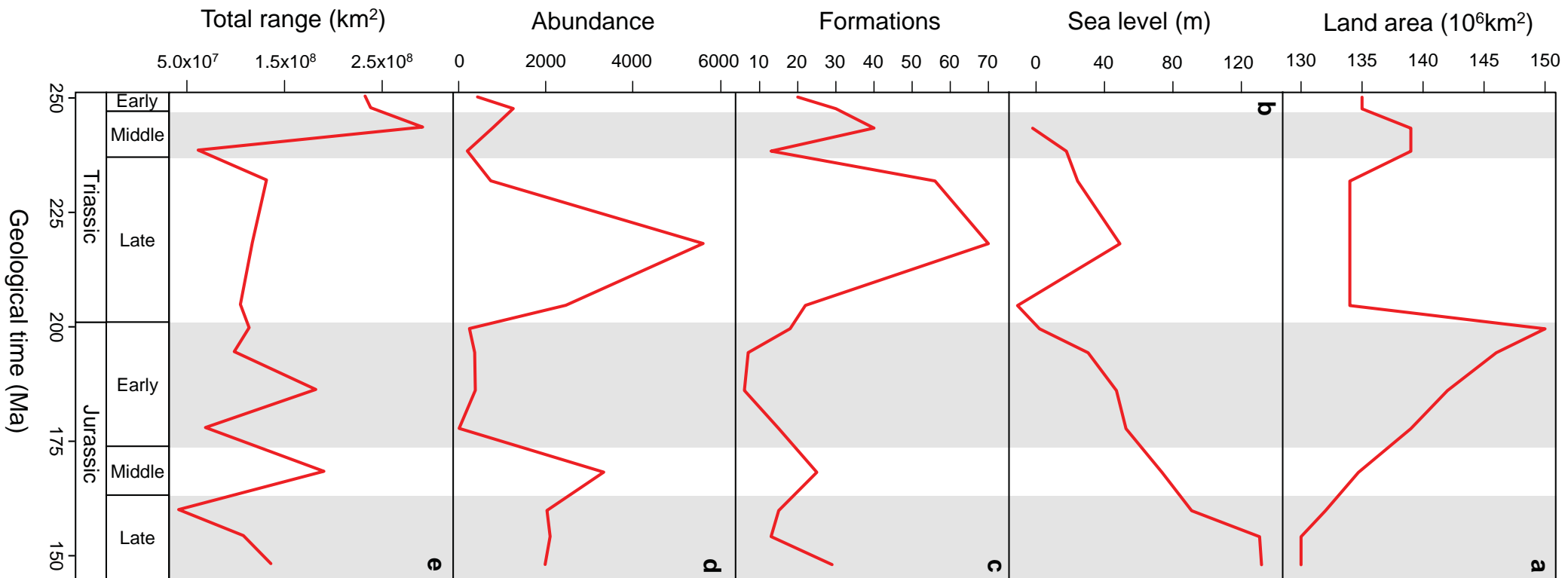




- 
Aetosauria
 Rhaetian: 1.832

 Hettangian: †
- 
Cynognathia
 Rhaetian: 1.337

 Hettangian: †
- 
Phytosauria
 Rhaetian: 6.967

 Hettangian: †



- 
Probainognathia
 Rhaetian: 13.23

 Hettangian: 10
- 
Sauropodomorpha
 Rhaetian: 12.503

 Hettangian: 15.935
- 
Theropoda
 Rhaetian: 5

 Hettangian: 5

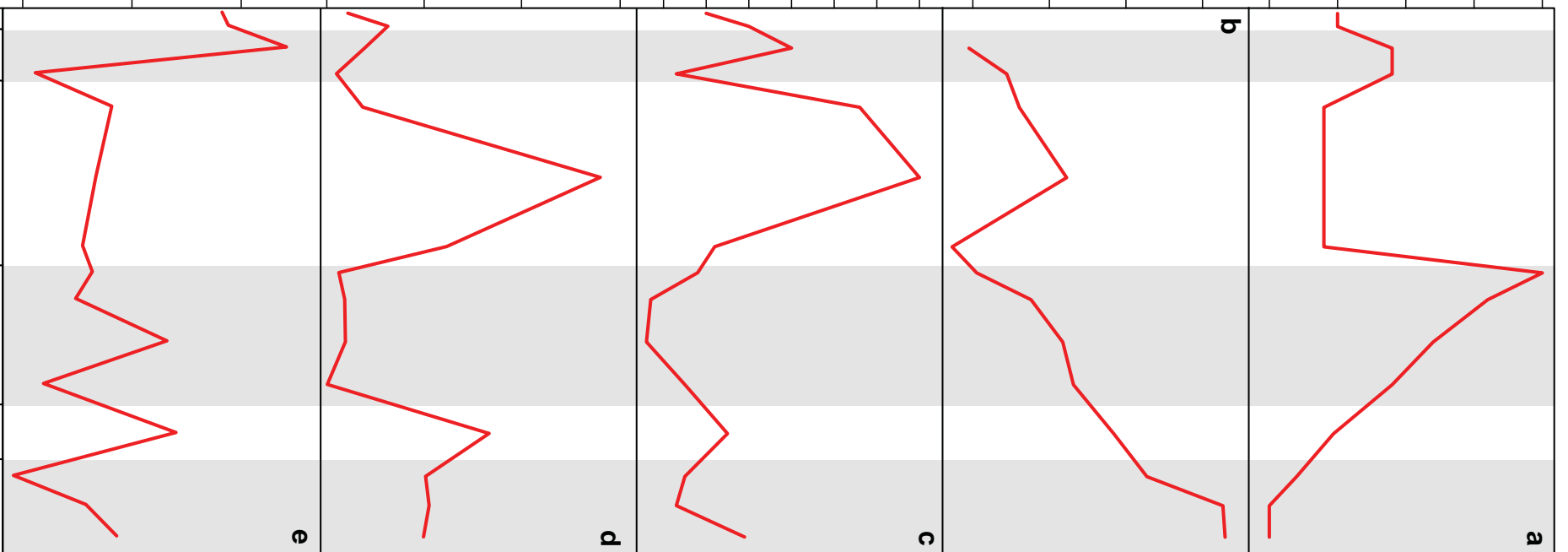


Geological time (Ma)

250
225
200
175
150

Early
Middle
Late
Early
Middle
Late

Total range (km²)
Abundance
Formations
Sea level (m)
Land area (10⁶km²)



e

d

c

b

a