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The Greatest Extinction Event in 66 Million Years?
Contextualising Anthropogenic Extinctions

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1 **The greatest extinction event in 66 million years? Contextualising anthropogenic**

2 **extinctions**

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Abstract

28   Biological communities are changing rapidly in response to human activities, with the high

29   rate of vertebrate species extinction leading many to propose that we are in the midst of a

30   sixth mass extinction event. Five past mass extinction events have commonly been identified

31   across the Phanerozoic, with the last occurring at the end of the Cretaceous, 66 million

32   years ago (Ma). However, life on Earth has always changed and evolved, with most species

33   ever to have existed now extinct. The question is, are human activities increasing the rate

34   and magnitude of extinction to levels rarely seen in the history of life? Drawing on the

35   literature on extinctions primarily over the last 66 million years (i.e. the Cenozoic), we ask:

36   (1) what comparisons can meaningfully be drawn? and (2) when did the Earth last witness

37   an extinction event on this scale? We conclude that, although challenging to address, the

38   available evidence suggests that the ongoing extinction episode still falls a long way short of

39   the devastation caused by the bolide impact 66 Ma, but that it has likely surpassed most

40   other Cenozoic events in magnitude, with the possible exception of the Eocene–Oligocene

41   transition (34 Ma), about which much uncertainty remains. Given the number of endangered

42   and at-risk species, the eventual magnitude of the current event will depend heavily on

43   humanity's response and how we interact with the rest of the biosphere over the coming

44   millennia.

1 INTRODUCTION

Human activities have resulted in rapid and far-reaching changes to global biodiversity (Ellis *et al.* 2021; Thomas 2020). This includes the extinction of almost two thirds of terrestrial vertebrate megafauna (Svenning *et al.* 2024; Turvey and Crees 2019), and the mass movement of species across the globe (Thomas 2020), with major impacts seen since at least the Late Pleistocene (~ 130,000 years ago) and forecast far into the future (Andermann *et al.* 2020; Davis *et al.* 2018; Ellis *et al.* 2021; Gordon *et al.* 2024; Matthews *et al.* 2024). Based on comparisons with background estimates from the fossil record, the rate at which species are currently going extinct has led many scientists to propose that we are now entering a sixth mass extinction (Barnosky *et al.* 2011; Ceballos *et al.* 2015; Leakey and Lewin 1995; Pimm et al. 2014). The Earth has experienced multiple climatic and environmental perturbations, including five such 'events' across the Phanerozoic (the last 541 million years) interpreted as mass extinctions. The most recent of these occurred at the Cretaceous/Paleogene (K/Pg) boundary, 66 million years ago (Ma). Uncertainty remains as to whether the current extinction rate and magnitude is indeed higher than at any time over the last 66 million years i.e. the Cenozoic (Barnosky *et al.* 2011; Cowie *et al.* 2022), and if they are already comparable to those associated with events such as the bolide impact that ended the age of the non-avian dinosaurs at the K/Pg boundary (e.g. Chiarenza *et al.* 2020) or the large-scale volcanic activity thought responsible for the end-Permian Great Dying, 252 Ma (e.g. Chen and Benton 2012). Put more simply, is the Earth currently experiencing a mass extinction event, or one only severe on human timescales? This is important to answer if we want to use the past as an analogue for understanding and predicting the scale of the ongoing biodiversity crisis, including recovery times and long-term ramifications to the biosphere.

71 More than 99% of all species that have ever existed are now extinct, with extinction being a

72 fundamental evolutionary process, however definitions and detections can prove challenging

73 (Jablonski 2004; Raup 1991). The exact timing of extinction is difficult to determine both in

74 the present and in the past (Purvis *et al.* 2000). The loss of a population from a particular

75 geographic area (i.e. local extinction or extirpation) may or may not be a precursor to global

76 extinction (Congreve *et al.* 2018), while knowledge of the distribution of all populations of a

77 species is also rare (e.g. Pearson *et al.* 2006). Species also become "functionally" extinct

78 long before this point. Functional extinction occurs when a population becomes so low that it

79 has limited impacts on other species, due to its rarity, and where recovery is no longer

80 realistic (e.g. due to various Allee effects or continued environmental changes that led to the

81 original decline [e.g. Säterberg *et al.* 2013]). Over longer time periods the issues of

82 pseudoextinction and Lazarus taxa are encountered. Pseudoextinction occurs when all the

83 members of a species are lost but their descendants survive as a daughter species,

84 highlighting the issue of species delineation, and the extent to which this is comparable

85 between fossil and living taxa (Raup, 1991). Lazarus taxa disappear from the fossil record,

86 assumed to be extinct, but are then detected in a later time period indicating a lack of

87 detection rather than genuine absence (Jablonski, 1986).

88 Here, we synthesise previous literature investigating both past extinctions and ongoing

89 biodiversity change to place the period of anthropogenic extinctions in the wider geological

90 context. To do this, we start by examining the events traditionally seen as the largest of all

91 extinction events – the five Phanerozoic mass extinctions. We follow this by discussing

92 extinction events over the last 66 million years, i.e. since the last mass extinction and when

93 Earth's ecosystems and biodiversity have been the most similar to those of the present day.

94 We then consider the anthropogenic extinction event, defined herein as spanning the last

95 interglacial (~ 130 ka) to the present. This represents the well-established time frame of

96 increasing human planetary influence, from the megafaunal extinction, through to the current

97 period where humans have modified the planet to such an extent that our influence is

98   inescapable (Thomas 2020; Svenning *et al.*, 2024). We then discuss the challenges of

99   making meaningful comparisons given the contrasting biases between the fossil record and

100   present-day biodiversity data, explore comparisons that can be made, and finish by

101   discussing what these mean for the future of biodiversity. By reviewing the evidence we

102   address the central hypothesis that the ongoing anthropogenic extinction event is

103   comparable in magnitude and rate to past events considered mass extinctions.

104   2 EXTINCTIONS PAST, PRESENT AND FUTURE

105   2.1 The 'Big Five'

106   Although there will always be species extinctions, some time periods are known for their

107   atypically high rates (extinction events), with the greatest of these being labelled 'mass

108   extinctions'. However, such events are difficult to define. One commonly cited definition of a

109   mass extinction event is a *"substantial increase in the amount of extinction suffered by more*

110   *than one geographically wide-spread higher taxon during a relatively short interval of*

111   *geologic time, resulting in an at least temporary decline in their standing diversity"* (Sepkoski

112   1986, p. 278). The ambiguity in this definition has led to more quantitative interpretations,

113   such as 75% of species becoming extinct in less than 2 million years (Barnosky *et al.* 2011).

114   Through their dramatic impact on both species and ecosystems over relatively (geologically)

115   short periods of time, these events have undoubtedly shaped the evolutionary history of life

116   on Earth across the past ~550 million years (Hull and Darroch 2013; McGhee *et al.* 2004;

117   Raup and Sepkoski 1982). Only five instances are believed to have been this devastating

118   and widespread and are often described as the 'Big Five' mass extinctions (Figure 1). These

119   events are: (1) the Late Ordovician mass extinction (~445 Ma); (2) the prolonged Late

120   Devonian mass extinction(s) (~370–360 Ma); (3) the Permian-Triassic mass extinction (~252

121   Ma); (4) the Late Triassic mass extinction (~201 Ma); and (5) the Cretaceous-Paleogene (K-

122   Pg) mass extinction (~66 Ma) (Raup and Sepkoski 1982).

123

124   The extent to which the 'Big 5' are genuinely distinct from other extinction events is debated,

125   given that the Phanerozoic has been punctuated by many smaller scale and often less well-

126   known extinction events (Raup 1986), with constantly fluctuating rates suggesting a

127   continuum of extinction episodes (Harper *et al.* 2020). Only the Late Ordovician, Permian-

128   Triassic and Cretaceous-Paleogene extinctions stand out on magnitude alone, with diversity

129   losses during the Late Devonian and Late Triassic being at least partially attributable to

130   reductions in origination rates (Bambach 2006). On the other hand, Bambach (2006)

131   identified at least 18 substage intervals across the Phanerozoic that could be seen as mass

132   extinctions using a marine genus-level compendium (Figure 1). This means that all

133   detectable spikes in extinction rate could be considered mass extinctions, or the term could

134   be reserved for the largest three (i.e. Late Ordovician, Permian-Triassic and Cretaceous-

135   Paleogene), which are distinct extinction anomalies even when accounting for various data

136   constraints (see 3).

137

138   Consideration must also be given to the other elements of the definition, i.e. multiple

139   geographically widespread higher taxa disappearing within a relatively short time (Sepkoski,

140   1986). This again has proven contentious, especially as most studies have been reliant on

141   compilations dominated by the best-preserved marine taxa (Figure 1), with terrestrial

142   extinction rates harder to quantify due to the sparser fossil record (e.g. Benson *et al.* 2021).

143   Some events not viewed as mass extinctions have resulted in significant global changes,

144   such as the Carnian Pluvial Episode (234 to 232 Ma), which saw the large-scale loss of

145   genera but also major diversification, resulting in substantial turnover (Dal Corso *et al.* 2020).

146   Many known extinction events are also more geographically or taxonomically restricted

147   (Arcila and Tyler 2017; MacLeod 1994), or primarily affected organisms with particular traits

148   (Aberhan and Baumiller 2003; Pimiento *et al.* 2017; Pym *et al.* 2023). Past diversity is

149   usually measured at the level of genera, rather than species, with the challenge of identifying

150   species, among other factors, resulting in the proliferation of genus- level palaeobiological

151   analysis (Hendricks *et al.* 2014). Conversion of genus level estimates into species loss

152   creates further complications, with factors such as the phylogenetic clustering of extinctions

153   having a major role (Stanley 2016). Uncertainty also arises because a widespread genus in

154   the fossil record could be represented by one of a few widespread species, or by very large

155   numbers of more localised species with different biogeographic ranges (Hallam and Wignall

156   1997).

157   Understanding the rate of extinction is as important as estimating its magnitude. The

158   'highest' temporal resolution that can be reliably reached for deep–time estimates such as

159   those used for the 'Big Five' is often on the order of hundreds of thousands to millions of

160   years (Erwin 2006). Particularly complete geological sections and advanced methodological

161   approaches have resulted in higher resolutions (e.g. Dean *et al.* 2020; Fan *et al.* 2020;

162   Lyson *et al.* 2019) but these are uncommon and difficult to correlate in order to gain a picture

163   of the rapidity of the event on a global scale. Extinction events are, however, increasingly

164   being perceived as pulses (Spalding and Hull 2021), which only appear to be gradual

165   (smooth) increases in extinction rates when averaged over longer periods of time. High

166   resolution data (i.e. comparable to that used when considering anthropogenic extinctions)

167   would capture these peaks in extinction rate, but coarser data (i.e. which characterises most

168   of the fossil record) would produce a lower rate, averaged over a longer period of time, as

169   extinction pulses would be inextricably combined with periods of low or background

170   extinctions. This issue has been shown to impact perceptions of deep-time fluctuations in

171   diversity, such as the decline in Cretaceous North American dinosaurs (Dean *et al.* 2020). In

172   other cases, an extinction event with a large magnitude (i.e. a large reduction in standing

173   diversity) might only have a limited impact on ecological processes at any given time if the

174   species turnover took place gradually over a long period. A slow decline in generic diversity

175   over one or more million years in the fossil record, for example, may represent a

176   recognisable anomaly, but might not be seen as an extinction event or crisis on a decadal to

177   millennial timescale (Bambach 2006). To try and resolve this, attempts have been made to

178   estimate the temporal duration of heightened extinction rates based on the hypothesised

179   causes. For example, the K-Pg event is considered to have been geologically instantaneous

180   because of the rapid cessation of photosynthesis caused by the consequent 'impact winter',

181   i.e. global cooling associated with the rapid release of sulphate aerosols (Morgan *et al.* 2022;

182   Schulte *et al.* 2010). The Late Ordovician, in contrast, is seen as at least two distinctive

183   pulses attributed to cooling, glaciation and changes in ocean chemistry (Harper 2024).

184   Defining mass extinctions and comparing events to one another is therefore a complex and

185   sometimes subjective process. Given the complex causes and consequences, even the

186   largest extinctions that we know of, the 'Big Five', are very different to one another and have

187   nuanced trajectories (e.g. Foster et al. 2023). Rate and magnitude changes alone are

188   unlikely to meaningfully capture the consequences of such events for Earth systems and the

189   biosphere. Attempts to categorise what is, in effect, a continuous scale may in this case not

190   be useful. This complexity and continuum of magnitudes of extinction 'events' complicates

191   discussions of whether the present day represents a potential 'Big Sixth' mass extinction,

192   and therefore the greatest extinction event in the last 66 million years. Nonetheless, it is

193   possible to conclude that all of the 'Big Five' mass extinctions were characterised by the

194   Earth's physical and then biological conditions deviating outside the range previously

195   experienced, leading many species to disappear in each case.

196   While there has been much debate on the threshold that defines a mass extinction

197   (Barnosky *et al.*, 2011; Marshall, 2023), there is even less consensus on what distinguishes

198   a smaller, non-mass extinction, from the 'normal' background rate of extinction. One

199   possibility is to consider extinction rates to constitute an 'event' when they substantially

200   exceed the background extinction rate but fail to reach the threshold of a mass extinction.

201   This definition is how we have selected smaller extinction events for discussion below.

202

203   2.2 The last 66 million years

204   The most recent mass extinction event took place at the end of the Cretaceous, heralding

205   the end of the Mesozoic and the beginning of the Cenozoic, 66 Ma. The large asteroid

206   impact in the Yucatán Peninsula of Mexico and subsequent wildfires resulted in dust,

207   sulphate aerosols, CO_2, soot and water vapour entering the atmosphere, which led to rapid,

208   extreme climatic cooling and ocean acidification (Chiarenza *et al.* 2020; Hull *et al.* 2020;

209   Morgan *et al.* 2022). An estimated 40% of genera and 76% of species were lost (Barnosky *et*

210   *al.* 2011), including the extinction of many vertebrate and invertebrate groups, most famously

211   the non-avialan dinosaurs and ammonites, although no taxonomic group passed through the

212   K/Pg boundary entirely unscathed (Hallam and Wignall 1997). The process was likely rapid

213   (Chiarenza *et al.* 2020), meaning that both the magnitude and rate of extinction were

214   extremely high.

215   Major losses in taxonomic groups that were dominant during the Cretaceous mean that

216   much of the floral and faunal composition of present-day ecosystems originated in the

217   Cenozoic (Finnegan *et al.* 2024). Although Cenozoic extinction events were of lower

218   magnitude than some others that preceded them, they are likely to have been the most

219   comparable to present-day extinctions in terms of the ecosystems and higher taxa involved.

220   As such, although we draw on deeper time comparisons, our primarily focus in this

221   contribution is on the Cenozoic.

222   The Cenozoic fossil record provides evidence for several extinction events since the K-Pg

223   event. Although not as devastating as the latter extinction, all of these appear to have been

224   taxonomically, environmentally, and geographically wide-ranging, with long-term

225   consequences for the biosphere (Figures 2-3). These are the Paleocene-Eocene Thermal

226   Maximum (~ 56 Ma), the Eocene-Oligocene transition (~ 34 Ma), and the Pliocene to

227   Pleistocene transition (~ 2.6 Ma) (Bambach 2006; Finnegan *et al.* 2024; Harnik *et al.* 2012).

228   The events defining the start and end of the Eocene resulted in substantial change in the

229   Earth's systems. The PETM saw rapid warming (> 5 °C global mean average increase) and

230   ocean acidification, attributed to volcanic carbon releases within < 10,000 years (Aze 2022;

231   Harnik *et al.* 2012; Haynes and Hönisch 2020; Tierney *et al.* 2022). This led to turnover in

232   many communities and elevated extinction rates for metazoan reef species (Kiessling and

233   Simpson 2011), calcareous nannoplankton (Gibbs *et al.* 2006), and benthic foraminifera

234   (Speijer *et al.* 2012). The event is perhaps most notable for the high magnitude of extinction

235   in the latter group, which had been relatively unscathed by the K-Pg event but suffered a

236   decline at the PETM (33 to 65% of species lost [Speijer *et al.* 2012]) unparalleled in the rest

237   of its Cenozoic timeline (Hallam and Wignall 1997). The current evidence suggests that

238   although geographically widespread (e.g. Babila *et al.* 2022), high extinction magnitudes

239   were restricted to marine taxa sensitive to the rapid warming, acidification, and

240   deoxygenation of oceanic water, with only limited evidence for terrestrial plant and mammal

241   extinctions (Clyde and Gingerich 1998; Jaramillo *et al.* 2006; Yao *et al.* 2018).

242   Global cooling at the end of the Eocene (~ 34 Ma) is believed to have caused the Eocene-

243   Oligocene extinction event (Harnik *et al.* 2012). In comparison with the PETM, there is more

244   evidence that both the marine and terrestrial realms were strongly affected, and the event

245   appears more clearly in fossil record analyses (Figures 1-2), but it is challenging to narrow

246   down the event's duration and the concurrence of regional changes. For example, elevated

247   extinction magnitudes are found for some groups of foraminifera, with planktonic forms

248   suffering one of their worst extinction events (Pearson *et al.* 2008; Lowery et al., 2020).

249   Foraminifera extinctions are estimated at less than 15% of species at the Eocene-Oligocene

250   boundary, but are higher when combined with other late Eocene extinctions (Keller 1986).

251   Similar patterns are reported for calcareous nannoplankton and molluscs, which both show a

252   drawn-out loss and turnover, with marine extinctions extended across an interval of at least 1

253   million years (Lowery et al., 2020) and perhaps up to 14 million years in duration for some

254   groups (Hallam and Wignall 1997). The diversity of early stem whales ('archaeocetes') also

255   appears to have declined across the Eocene-Oligocene transition (Corrie and Fordyce

256   2022). In the terrestrial realm, there is evidence for relatively rapid continental-scale

257   extinctions in mammals (de Vries *et al.* 2021; Hooker *et al.* 2004; Weppe *et al.* 2023), with

258   magnitude estimates for western Europe's endemic artiodactyls being as high as 77% of

259   species (62% genera) lost over a million-year period (Weppe *et al.* 2023). There is also

260   evidence for diversity declines in reptilian groups, at least in Europe and North America

261   (Cleary *et al.* 2018; Mannion *et al.* 2015). Increased extinction in South American plants has

262   also been documented (Jaramillo *et al.* 2006). Overall, however, evidence points towards a

263   prolonged, and potentially spatially heterogeneous, species turnover in response to global

264   cooling and changing aridity (Hallam and Wignall 1997; Mannion *et al.* 2015; Sun *et al.*

265   2014).

266   Global cooling again coincided with elevated extinction rates as the Pliocene transitioned

267   into the Pleistocene (2.6 Ma), with marine megafauna particularly strongly affected. It is

268   estimated that 36% of the Pliocene marine megafaunal genera did not survive into the

269   Pleistocene (Pimiento *et al.* 2017). Localised extinctions at the end of the Pliocene have also

270   been noted for Caribbean molluscs and corals (Pimiento *et al.* 2020; van Woesik *et al.*

271   2012), as well as the loss of many terrestrial African megaherbivores (Bibi and

272   Cantalapiedra 2023) and benthic foraminifera (Hayward *et al.* 2007). Again, however, it is

273   difficult to currently identify a major global event, with extinctions unfolding over multi-million-

274   year time scales.

275   In summary, the current evidence suggests that many of the perceived extinction events in

276   the Cenozoic may have been a drawn-out series of localised and shorter-term events that, in

277   combination, resulted in large global turnover. The K-Pg and Eocene-Oligocene have the

278   clearest evidence for impacts across a wide range of taxa and environments as well as the

279   highest magnitude. The K-Pg and PETM, however, are the strongest candidates for

280   relatively rapid rates meaning that changes in the global flora and fauna may have been

281   perceivable on time scales more similar to those thought to characterise the proposed

282   present-day 'sixth mass extinction'.

2.3 The anthropogenic 'sixth mass extinction'

A fundamental question is precisely when *Homo sapiens* started to significantly alter global systems and cause a spike in species extinctions. There are multiple phases of influence throughout the evolution of humans but, for many, the earliest evidence of anthropogenic disturbance is denoted by the extinction of the terrestrial megafauna. This starting point is not, however, free of controversy as it relies on resolving the major drivers behind the Late Pleistocene extinctions. Nearly two thirds of megafaunal vertebrate genera (> 44 kg) became extinct by the end of the Pleistocene (11.7 ka) (Turvey and Crees 2019; Svenning *et al*., 2024). Although this extinction rate is relatively high and the global impacts broad, the overall magnitude of this initial wave of extinction was limited due to its taxonomic and trait-based (body size, terrestrial) selectivity. Whilst the temporal co-occurrence of the extinctions with the spread of *Homo sapiens* across Earth's surface heavily implicates humans as a significant contributor to the event (Barnosky *et al.* 2004; Lemoine *et al.* 2023), the extent of the role of the individual versus combined contributions of climate versus human hunting and landscape modification (e.g. O'Keefe *et al.* 2023) in the late Pleistocene megafaunal extinction event is still debated, especially in relation to the fates of individual species (Lemoine *et al.* 2023; Seersholm *et al.* 2020; Stewart *et al.* 2021).

During the early Holocene (Holocene: 11.7 ka to present) humans spread to increasingly isolated islands. People, along with their commensals, such as nest predating rats, reached even remote islands, finding large numbers of island endemics (e.g. flightless birds) vulnerable to these new threats. Humans are thought to have expanded across the Pacific in the last 3.5 ka (Matisoo-Smith *et al.* 1998) and into East Polynesia within the last 1 ka (Wilmshurst *et al.* 2011), with the estimated extinction of ~1,000 bird species (and any obligate parasites) resulting from human colonisation (Duncan *et al.* 2013). Recent estimates of global bird extinctions consider that ~ 12% of bird species (1,300 - 1,500) have become extinct in the last ~ 130 ka with the majority of these being island species (Cooke *et al.* 2023; Matthews *et al*., 2024). Island mammals were also lost, with regions such as the Caribbean

310   and Madagascar strongly affected (Turvey 2009; Turvey and Crees 2019). In some cases,

311   both the largest and smallest species became extinct, potentially in response to different

312   drivers (Hansford *et al.* 2012). This combination of drivers expanded the taxonomic and

313   geographic breadth of extinctions, overall contributing to a larger magnitude event. As

314   human populations and transport capabilities increased during the modern period (post-

315   1500), hunting and the spread of human-associated species continued, leading to further

316   extinctions (Turvey 2009; Turvey and Crees 2019). An increasing number of species were

317   transported by trade and other human activities, with major increases in inter-regional

318   spread after 1800 AD (Seebens et al., 2021). This was compounded by the acceleration and

319   globalisation of habitat loss, as land was cleared for livestock, agriculture, and settlements

320   (Gordon *et al.* 2024; Mottl *et al.* 2021).

321   The high prevalence of localised island species among the list of human caused extinctions

322   raises issues of how these waves of extinction will be seen through the fossil record. The

323   magnitude of the current extinction rate would be underestimated by 66 to 98%, as nearly

324   30% of tetrapod species have little chance of fossilisation as they are not located in areas

325   with long-term deposition (Krone *et al.* 2024). This underlines the fact that differences in

326   preservation potential in the fossil record introduce biases as to which groups of organisms

327   can effectively be studied and compared (Sansom *et al.* 2010). It is also clear that apparent

328   extinctions in the fossil record may actually be periods of persistent rarity where a taxon is

329   simply no longer detected due to reduced abundance (Hull et al 2015).

330   2.4 An uncertain future

331   The Bramble Cay melomys (*Melomys rubicola*) is the first mammal species for which its

332   extinction has been almost entirely attributed to anthropogenic climate change, as erosion

333   and storms beset its only known island population (Waller *et al.* 2017). Climate change,

334   including severe weather, has already been implicated in the extinction (or extinction in the

335   wild) of at least 41 species (IUCN 2024). A meta-analysis considering published estimates of

336   extinction risk and representative concentration pathways for the 21st century, predicted that

337   3°C warming will result in an estimated 8.5% of species becoming extinct, with a rise of

338   4.3°C increasing this to 16% (Urban 2015). Indeed, groups that have exhibited high

339   extinction rates under climatic change in the past such as foraminifera are already starting to

340   show declines in abundance and biomass as well as range shifts (Chaabane et al., 2024;

341   Ying et al., 2024). Alongside climate change, land and sea use, as well as human

342   appropriation of net primary productivity, continue to rapidly change the planet. Future

343   biodiversity is therefore highly dependent on socioeconomic scenarios.

344   Using diverse sets of these socioeconomic trajectories of human development and policy

345   choices, several studies have explored future biodiversity trends, often finding an

346   acceleration of extinction rates attributed to land-use and climate change (IPBES 2016;

347   Pereira *et al.* 2010, 2024), but they also have been hampered by modelling and data

348   limitations. Existing scenario studies often use a single model, analyse a single facet of

349   biodiversity, or use different projections for future land-use and climate when comparing

350   multiple models (IPBES 2016). It is therefore not surprising that the sources of uncertainty in

351   these scenarios are numerous and difficult to ascertain (Thuiller *et al.* 2019). A recent

352   extensive model intercomparison (Pereira *et al.* 2024) showed that, even when controlling

353   for some of these aspects, substantial variation in outcomes can still be linked to both our

354   choice of models and projections. Since these models, and similar studies, used different

355   sources of biodiversity and driver data of varied structure, resolution and coverage (e.g.

356   taxonomic, temporal, spatial), it is unsurprising that current predictions of extinction risks

357   also vary widely depending on the focus of each study. Nonetheless, despite the large range

358   of estimated extinction levels, nearly all projections indicate large numbers of additional

359   species-level extinctions, but none of them predicts extinction levels as high as 75% of

360   species (given current, known threats).

361   Assuming losses of all threatened species, added to those already extinct (or extinct in the

362   wild) since 1500 AD, Barnosky (2011) estimated species losses of on average 32% (ranging

363   from 14% in birds to 64% in cycads). Using a Late Pleistocene baseline, Davis *et al.* (2018)

364   estimated that a century from now we will have lost 16% of mammal species over the last

365   130 ka. These estimates, however, require many assumptions, predominantly that current

366   extinction probabilities and rates will continue, and that IUCN categories are largely

367   accurate. Barnosky *et al.* (2011) took this further and asked how long it would take for the

368   percentage of species lost to reach mass extinction levels, i.e. 75% species losses.

369   Assuming the loss of all threatened species within the first century with high rates still

370   continuing after, a mass extinction would be reached for terrestrial amphibians, mammals,

371   and birds in ~ 240 to 540 years. If only Critically Endangered species were lost over 500

372   years followed by rate continuation, estimates range from 4,450 to 11,330 years across

373   groups for the 75% threshold to be reached (Barnosky *et al.* 2011). A range of estimates has

374   been produced by different studies depending on the data and assumptions made (Wiens

375   and Saban, 2025). On this basis, for mass extinction levels to be reached, high extinction

376   rates must be maintained for either a few centuries or a few millennia, depending on the rate

377   at which already threatened species are lost. However, this likely requires new threatening

378   processes, extinction cascades or ecosystem tipping points to emerge in future, given that

379   high rates would need to continue even after the loss of all currently threatened species to

380   reach the 75% threshold for assessed groups (Wiens and Saban, 2025). Unknown

381   extinctions also clearly hamper the accuracy of any estimates (Cowie et al., 2025). Future

382   scenarios are highly uncertain, and this hinders our ability to predict future extinction risk,

383   particularly when many of the relevant processes are likely non-linear. It is clear therefore

384   that projections of a sixth mass extinction are heavily contingent on the assumptions made.

385   The other side of this coin is speciation. Humans have moved species around the planet

386   across distances and at rates exceeding those of past biotic interchanges such as the Great

387   American Biotic Interchange (Stigall 2019). As these new populations adapt to novel

388   surroundings, they often contribute to the extinction of other species, as evidenced by our

389   discussion of island extinctions above; furthermore, it is estimated that introduced species

390   have contributed to 25% of plant extinctions and 33% of animal extinctions documented by

391   the IUCN (Blackburn et al., 2019). They might also be expected to form new species over

392   time, a process that could be accelerated by the strength of anthropogenic selection

393   pressures and hybridisation (Thomas 2015). However, the extent to which this could offset

394   losses is heavily debated (Hulme *et al.* 2015; Thomas 2015). New species may compensate

395   to some extent for taxonomic and functional diversity but are unlikely to replenish the loss of

396   global phylogenetic diversity for an extended period (Faurby *et al.* 2022). On million-year

397   time scales, heightened speciation rates are hypothesised as ecosystems recover in the

398   aftermath of extinction events (Chen and Benton 2012), as empty niche space is refilled.

399   How such a mechanism could operate under the rapid anthropogenic drivers of change is

400   unknown, especially as niche space and resources have been disproportionately channelled

401   from many species into one, i.e. *Homo sapiens*. In sum, conservation of at-risk species and

402   the resilience of remaining species will likely reduce species-level extinction rates, but

403   extinction will undoubtedly continue under ongoing climatic changes, ongoing species

404   introductions, and as-yet unimagined future human pressures.

405   **3 BIASES AND UNCERTAINTY**

406   The structure of the available fossil record (Holland 2017), and the subsequent sampling of

407   fossil material from it, fundamentally impacts what we can ascertain about past extinctions

408   (Signor and Lipps 1982). Accurately comparing ecosystems through time is a substantial

409   challenge that requires comprehensive consideration of fossil record biases, i.e. biological,

410   environmental and research biases which systematically and non-randomly skew the

411   available fossil record (Alroy 2010; Nanglu and Cullen 2023; Raup 1972). Understanding

412   and addressing these biases is therefore essential for us to accurately quantify past

413   extinction rates, and make clearer comparisons with those of the present and future.

414

415   3.1 Temporal inconsistency

416   At a fundamental level, the deposition of fossil-bearing rocks is driven by a variety of

417   geological and environmental factors that are non-continuous and non-evenly distributed

418   across space and time (Holland *et al.* 2022; Smith and McGowan 2007). Rocks that are

419   preserved are prone to destruction in non-uniform ways (e.g. subduction), producing a

420   geological record that is incomplete, temporally and spatially coarse, and uneven (Benson *et*

421   *al.* 2021; Vilhena and Smith 2013; Wagner and Marcot 2013). Subsequent sampling

422   processes of fossiliferous material from this record further exacerbates information distortion,

423   with geographic and societal (Raja *et al.* 2022) factors substantially impacting our perception

424   of past events.

425

426   All of these factors have particularly noticeable effects on estimation of the rates and

427   durations of 'events' (Kemp and Sexton 2014). A lack of available data can result in

428   'contentious' extinction events, either through an inability to distinguish between poor

429   sampling within an interval or a loss of species (e.g. Ediacaran extinctions, Hoyal Cuthill

430   2022; Jurassic-Cretaceous boundary, Tennant *et al.* 2017). In addition, the synthesis

431   required to detect large-scale events is hampered by the differences in temporal sampling

432   between different studies which have a substantial impact on measuring diversity through

433   time (Dean *et al.* 2020; Gibert and Escarguel 2017; Guillerme and Cooper 2018; Smith *et al.*

434   2023).

435   The timing of extinction is highly dependent on the definition of the taxonomic entity being

436   described: this means that inferred extinction rates can be affected by differences in species

437   definitions between clades, and between living and fossil taxa. In its most extreme form,

438   modern phylogenetic methods have resulted in the ability to split species based

439   predominantly on their genetic diversity, an option not open for fossil remains. As already

440   discussed, the majority of paleobiological studies are focused at the genus level (Hendricks

441   et al., 2014), in contrast to present-day biodiversity which is typically discussed in terms of

442   species. Our varying ability to resolve different taxonomic groups to species level also has a

443   temporal effect in of itself, as the relative frequency of these groups has not been consistent

444   over time - this, combined with heterogenous preservational biases, means that the diversity

445   of certain taxonomic groups is more difficult to estimate than others, providing a challenge to

446   global biodiversity estimates as clades wax and wane. There are also clear temporal

447   patterns in terms of which groups are studied, and these issues are not restricted to

448   paleontological analyses; most studies of current biodiversity are also taxonomically limited

449   (Cowie et al., 2025; Mammola et al. 2023; Wiens and Saban, 2025). One such challenging

450   issue for comparison is our lack of knowledge on modern marine extinctions (Harnik et al.

451   2012; Monte-Luna et al. 2023), whereas enumeration of many extinction events in deep time

452   relies on changes in marine genera due to their relatively high preservation potential

453   (Plotnick et al. 2016).

454

455   3.2 Spatial inconsistency

456   Spatial heterogeneity in fossil data can generate uncertainties that are as large as those

457   associated with temporal gaps in the geological record (Allison and Briggs 1993; Antell *et al.*

458   2024; Close *et al.* 2020; Vilhena and Smith 2013). The number, spread, and size of

459   geographic regions and environments that are represented in the fossil record varies

460   substantially and non-uniformly through time, and the subsequent sampling of these

461   localities is impacted by historical legacies (Raja *et al.* 2022). This changing patchwork of

462   spatial data has a substantial impact on our understanding and interpretation of extinction

463   events. Given that the geographic distributions of species and ecosystems have responded

464   to changing environmental conditions throughout time, there is a risk of conflating ecological

465   and evolutionary adjustments to the new conditions with global extinction. For example, did a

466   species become extinct between two successive time periods, or is its preferred environment

467   no longer represented in the fossil record (Smith *et al.* 2001)? Conversely, an integrated

468   fossil record at the global scale may underestimate the magnitude of regional changes

469   (Flannery-Sutherland *et al.* 2022). Particular latitudes also show correlated increases in

470   outcrop area, diversity and collector effort during different time intervals, impacting our ability

471 to understand macroecological patterns such as the latitudinal diversity gradient (Allen *et al.*

472 2020; Allison and Briggs 1993; Jones *et al.* 2021; Vilhena and Smith 2013).

473

474 **4 MEANINGFUL COMPARISONS**

475 To compare extinction events requires consideration of the available data quality,

476 magnitude, duration, and selectivity of each extinction event. To make future predictions we

477 must also consider common drivers: which influences are known to be able to cause major

478 shifts in the biosphere? It is difficult to both understand past extinction events and, perhaps

479 more importantly, to make fair and meaningful comparisons between extinction events (e.g.

480 Tomašových *et al.* 2023). Although methodological approaches exist to combat at least

481 some of these biases (e.g. PyRate, subsampling, spatial partitioning (Close *et al.* 2018;

482 Silvestro *et al.* 2014; Tibshirani 1994; Allen *et al.* 2025)), the drawing of well-supported

483 comparisons between different time periods is always likely to remain heavily caveated.

484 Because it is clear that our knowledge is incomplete, we therefore need to be circumspect

485 and make the most of the multiple lines of evidence that are available.

486

487 4.1 Extinction drivers

488 The extent to which the drivers of extinction in deep time are comparable to human-induced

489 environmental changes in the present is debated (e.g. Otto (2018)). For example, although

490 greenhouse gas emissions play a key role in both present and past climatic changes, how

491 comparable are the volume and rate (Foster *et al.* 2018)? Although the sources of

492 atmospheric changes differ (e.g. fossil fuels versus volcanic activity), it is clear that warming

493 has been a key extinction driver in most major past events, with accompanying acidification

494 and anoxia in the oceans (Bond and Grasby 2017; Calosi *et al.* 2019; Harnik *et al.* 2012).

495 This underlines the importance of emissions to the unfolding extinction event. Other

496 similarities can also be observed: for example, large community restructuring has occurred

497 in past biotic interchanges (i.e. during the exchange of species when barriers between

498   separated landmasses or oceans are removed), which parallels anthropogenic species

499   introductions; however, the rate and volume are likely far greater at present (McGhee *et al.*

500   2013; Vermeij 1991). Other anthropogenic drivers are more difficult to match with past

501   extinction events. The degree of novel predation generated by humans may have some

502   parallels in past biotic interchange but the rate and extent are likely uniquely high. The rapid

503   and extensive changes in land and sea-use (human versus Earth system mediated) are

504   probably only surpassed by cataclysms such as the K-Pg event, with other events

505   experiencing these on far slower timescales. However, many of the key measures and

506   consequences of extinction events have similarities between the present day and those seen

507   in the geological record.

508   4.2 Extinction magnitudes

509   The magnitude of an extinction event is often calculated as the proportional reduction in the

510   number of taxa (e.g. genera or species) or the proportion of taxa surviving into the time bin

511   or period after an event (Table 1, Figure 2). Mammals provide our highest resolution

512   information on anthropogenic extinctions. The PHYLACINE database (Faurby *et al.* 2020)

513   records 1,400 known mammal genera over the last ~130 ka. Only 1,245 of these are

514   estimated to still be extant in the wild, giving an approximate loss of 11% of mammal genera

515   globally. This is less than the 62% genus loss estimated for western European endemic

516   artiodactyls across the Eocene-Oligocene transition (Weppe *et al.* 2023), but the latter is

517   only a subset of the late Eocene mammal fauna, whereas the 11% loss of Recent mammal

518   genera is a global estimate. The latter is also less than the 36% loss of Pliocene marine

519   megafaunal genera (Pimiento et al. 2017). However, when we only consider megafauna

520   (genera > 45kg; Malhi *et al.* 2016) in our estimate of Recent mammalian losses (43%), this

521   exceeds that of the Pliocene. The original value of 11% would also exceed the 8% estimate

522   of genus extinctions outside of peak Cenozoic intervals, and not be far short of the 16% late

523   Eocene genus extinction reported by Bambach (2006). However, data comparability is again

524   an issue: Bambach's (2006) estimates are across a wide range of marine taxa and not just a

525   single group, and they do not account for sampling heterogeneity. Raw proportions of genus

526   extinction based on all taxa and across just mammals and reptiles in the Paleobiology

527   Database (https://paleobiodb.org/ [accessed 23rd April 2025]) also indicate very high losses

528   at the end of the Eocene, a pattern that holds across multiple measures (Figure 2). These

529   are, however, based on 5 million year time bins, with this coarse resolution allowing more

530   extinction accumulation as the time period is longer. Such comparisons show some of the

531   issues already highlighted around the challenges of comparison between past and present

532   data.

533   4.3 Extinction rates

534   We would expect the 130 kyr time scale used here for anthropogenic extinctions to be short

535   compared to some other documented extinction events. However, the duration and

536   dynamics of past extinctions are mostly unresolved, with some authors estimating a similar

537   100 kyr scale duration for the PETM (Molina 2015; Speijer *et al.* 2012). The K-Pg is thought

538   to have had a more rapid extinction rate, with most extinctions happening over a very short

539   duration due to the impact winter caused by the bolide (Chiarenza *et al.* 2020; Marshall

540   2023). Late Triassic extinction rates may also have been underestimated 100-fold if its

541   duration was 50,000 years rather than seven million years (Marshall 2023). Since 'short-

542   sharp' events of 100,000 or fewer years tend to become temporally averaged into 'longer-

543   gradual' geological events in the fossil record, it is extremely difficult to draw firm conclusions

544   about the tempo of most past mass extinction events. Rate-duration deductions therefore

545   inevitably come with high levels of uncertainty. This is especially true for many of the

546   estimates used to examine the 'Sixth mass extinction', with most authors focusing on just the

547   wave of extinctions that have taken place over the last 500 years (e.g. Ceballos *et al.* 2015),

548   a drastically different temporal resolution to the baseline data used as a comparator (Wiens

549   and Saben, 2025). Rate analyses indicate that the K-Pg event and the start and end of the

550   Eocene saw the highest extinction rates (Figure 2), but their duration is uncertain and

551   therefore currently not comparable to the modern record. Such drastic differences in

552   temporal resolution make solely quantitative comparisons highly unreliable, unless enforced

553   with other contextual information such as drivers and mechanisms.

554   4.4 Extinction selectivity

555   Another key aspect traditionally used to compare events is extinction selectivity. Range size

556   is considered a key attribute, with some evidence that geographically restricted species are

557   usually at higher risk. This, however, does not appear to hold consistently across all mass

558   extinctions (Dunhill and Wills 2015; Foster *et al.* 2023; Payne *et al.* 2023). The current event

559   shows a preferential loss of small ranged species, with the loss of island endemics being a

560   prominent example (e.g. Cooke *et al*. (2023)), but extinctions from small oceanic islands and

561   of small ranged species in general are typically not detected in the deep time fossil record

562   (Plotnick *et al.* 2016). However, earlier waves of anthropogenic extinction such as the loss of

563   the terrestrial megafauna, resulted in the loss of once widespread species, and population

564   trends over the last few decades cannot be explained by geographic range size (Daskalova

565   *et al.* 2020; Malhi *et al.* 2016). Range contractions and population reductions in widespread

566   species can result in more species being rare. This may leave them more vulnerable to

567   extinction in future, but in turn, would also likely result in fewer species being preserved,

568   which would be perceived as a mass extinction by future paleobiologists working only with

569   the fossil record (Hull et al 2015). Body size selectivity is often identified with anthropogenic

570   extinctions (Purvis *et al.* 2000), again exemplified by the terrestrial megafaunal extinctions.

571   However, this link between body size and extinction is not seen in all events (Monarrez *et al.*

572   2021; but see K-Pg; Payne *et al.* 2023). Assessing these factors mechanistically, both body

573   size and range size are related to demography, with large species and those with restricted

574   ranges usually having smaller populations, and, in the case of large species, lower

575   reproductive rates. Smaller populations and reduced ability to rapidly replenish them make

576   species susceptible to overharvesting, which is perhaps a unique driver to the current

577   extinction event.

578 The spatial extent and intensity of human influence means that extinctions are unlikely to be

579 confined to a particular taxonomic group or geographic location, and that current patterns of

580 selectivity may not hold as the event increases in magnitude. For example, amphibian

581 extinctions due to infection by chytrid fungus are not specifically associated with body size. A

582 high-magnitude, high-selectivity event would require very high extinction proportions in some

583 taxonomic or functional groups, combined with extremely low values for others (Bush *et al.*

584 2020). As the magnitude increases, the chances of losing higher taxonomic groups

585 increases under a random process ('Field of bullets' (Raup 1991)), but for this to be

586 achieved at lower magnitudes, the process would have to differ strongly from random (i.e.

587 some form of selectivity). However, as yet, no clear patterns in the degree or type of

588 selectivity have been found in common across mass extinctions (Bush *et al.* 2020; Foster *et*

589 *al.* 2023; Payne *et al.* 2023).

590 4.5 Biosphere regime shift

591 When considering anthropogenic extinctions, the loss of the megafauna and the processes

592 they regulated can be seen as part of a simplification and homogenisation of the biosphere

593 (Fraser *et al.* 2022). In addition to this early wave, simplified and often homogenised

594 ecosystems across the globe are widely documented today (Daru *et al.* 2021). Current

595 homogenisation is attributed to increasingly widespread generalist taxa (McKinney and

596 Lockwood 1999), as well as species able to prosper on a highly human-dominated globe

597 (Carroll *et al.* 2023). In addition, many species have become globally widespread due to

598 direct human transportation across the world. This bears strong similarities to the "disaster

599 faunas" of the past (Button *et al.* 2017), with generalist species thriving in the wake of

600 extinction events. Perhaps the most famous example is *Lystrosaurus*, a bulky herbivore that

601 became dominant following the end-Permian mass extinction (Sahney and Benton 2008).

602 Other changes in species community complexity and structure could result from cascading

603 effects through food webs and other forms of species interaction (e.g. mutualisms and

604 competition), which are of mounting concern for current conservation efforts. Looking at past

605   extinctions, trophic cascades have been discussed as a potential mechanism exacerbating

606   the K-Pg event (Alvarez *et al.* 1980), but it has proven difficult to quantify (Roopnarine 2006).

607   Community and ecosystem restructuring is also studied by the analysis of changes in

608   functional space, altering the range of ecological roles filled. Loss of functional space and

609   particular functional groups is widely seen in the current extinction event and in predictions

610   of future extinction risk (Carmona *et al.* 2021; Hatfield *et al.* 2022; Sayol *et al.* 2021).

611   Although evidence is mixed on whether past extinctions removed entire functional groups

612   (Dineen *et al.* 2014; Edie *et al.* 2018; Foster and Twitchett 2014), they did reduce functional

613   redundancy, with fewer species performing any particular function (Pimiento *et al.* 2017,

614   2020). In the cases of the end-Permian and end-Cretaceous mass extinctions, regime shifts

615   are thought to have taken place, with pre-extinction and post-extinction faunas and floras

616   having different structures, for example the restructuring of tropical forests post K-Pg

617   (Carvalho *et al.* 2021; Feng *et al.* 2020). Human activities have disrupted long-standing

618   vertebrate size structure patterns (Cooke *et al.* 2022) and created a mammalian biomass

619   overwhelmingly composed of humans and domesticates (Greenspoon *et al.* 2023). This

620   represents a large-scale restructuring of the biosphere with such levels of reorganisation

621   perhaps not seen since the recovery from the K-Pg.

622   **4 CONCLUSIONS**

623   The available evidence suggests that the current extinction rate is approaching or even

624   surpassing that seen across earlier Cenozoic events, at least for certain groups. Both the

625   taxonomic and geographic breadth also appears to be greater than other Cenozoic events

626   and it is clear that human influence has grown rapidly and become global. The magnitude

627   recorded so far, however, suggests that anthropogenic extinctions are still far below that of

628   the larger pre-Cenozoic mass extinction events, such as those that marked the end-Permian

629   and end-Cretaceous. The Eocene-Oligocene transition, 34 million years ago, appears to be

630   the nearest contender for the largest Cenozoic extinction event, but comparison to the

631 current anthropogenic extinction event is heavily hampered by the lack of high resolution

632 data. Nevertheless, the available evidence suggests that the Eocene-Oligocene event

633 occurred on a million-year timescale and was staggered spatiotemporally and taxonomically.

634 Comparisons of extinction events across deep time will always remain deeply caveated and

635 uncertain though, even with rapidly improving methods and accumulating data. However, the

636 future of anthropogenic pressures are also highly uncertain and are not expected to subside

637 for at least many decades, and some, such as climatic change, are expected to increase.

638 The current extinction event is still unfolding, and whether the severity reaches that seen in

639 the past will depend heavily on the fate of species now rare or otherwise considered at risk.

640 As we move forward, the amount of anthropogenic sea/land-use and climatic change will

641 have a substantial impact on the magnitude of the current extinction event. Precluding major

642 reductions in the current extinction rate, we are witnessing what will become the greatest

643 extinction event since the demise of the non-avialan dinosaurs 66 million years ago; whether

644 we see a mass extinction remains a choice yet to be made.

Author contribution statement

655 JHH and KED drafted the first version of this manuscript. All authors contributed to workshop

656 discussions, the drafting of individual sections and provided edits and suggestions for the

657 final version.

658 **Conflict of interest statement**

659 None

660 **Data availability statement**

661 Sepkoski's compendium (Figure 1) was reproduced using the R package sepkoski. Genus

662 level records were from the Paleobiology Database https://paleobiodb.org (Downloaded 23rd

663 April 2025) and plotted (Figure 2) using the R package divDyn.

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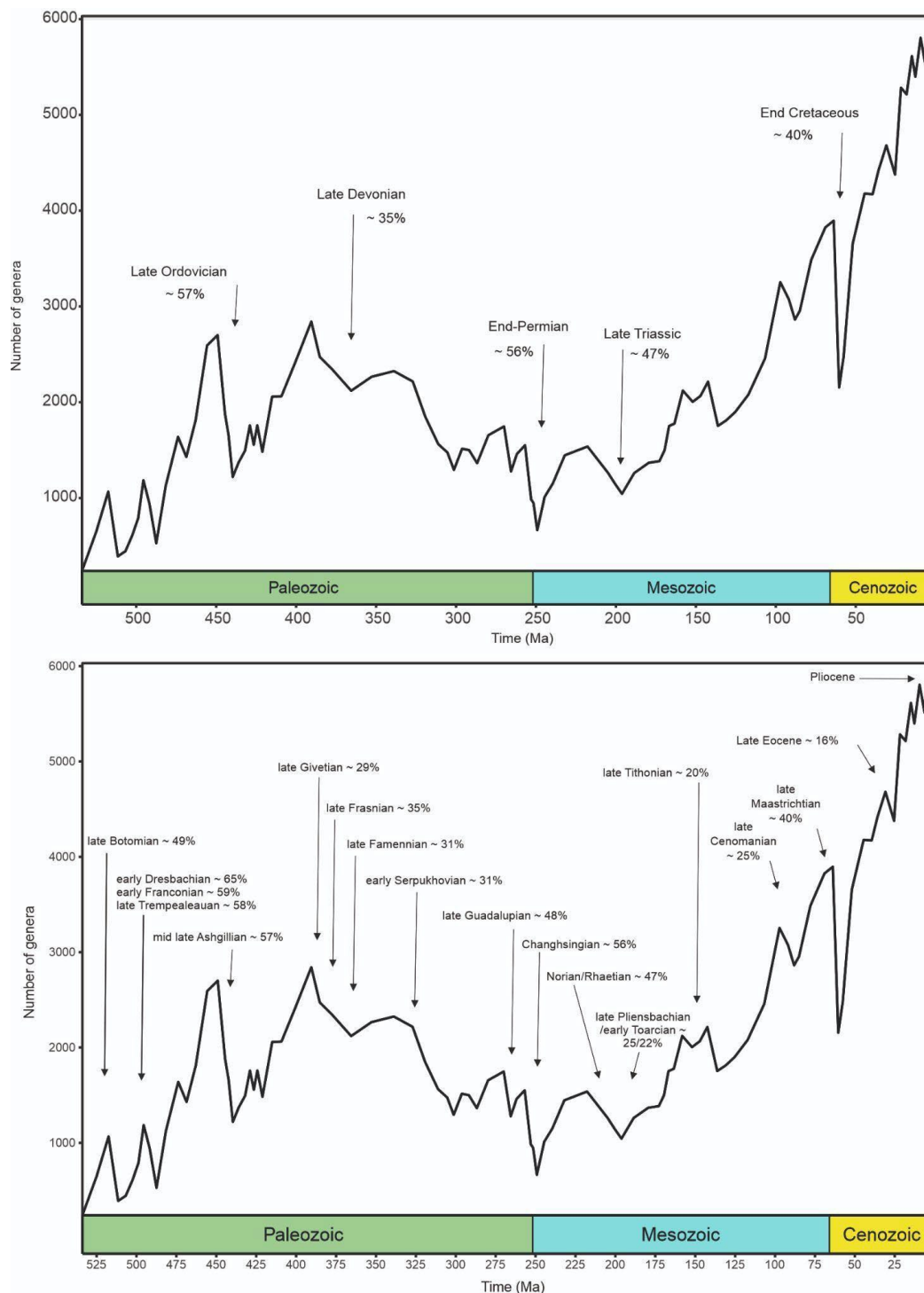
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FIGURE 1 - Number of fossil marine animal genera over the Phanerozoic based on Sepkoski's compendium (Peters 2022; Sepkoski 1981, 2002). Reproduced using the R packages sepkoski (Jones 2022) and deeptime (Gearty 2024). In the top panel the arrows indicate the Big Five mass extinction events with estimates of the percentages of genera becoming extinct. The bottom panel shows the 18 sub-stage intervals identified by Bambach (2006). A percentage of extinct genera was not given for the Pliocene.

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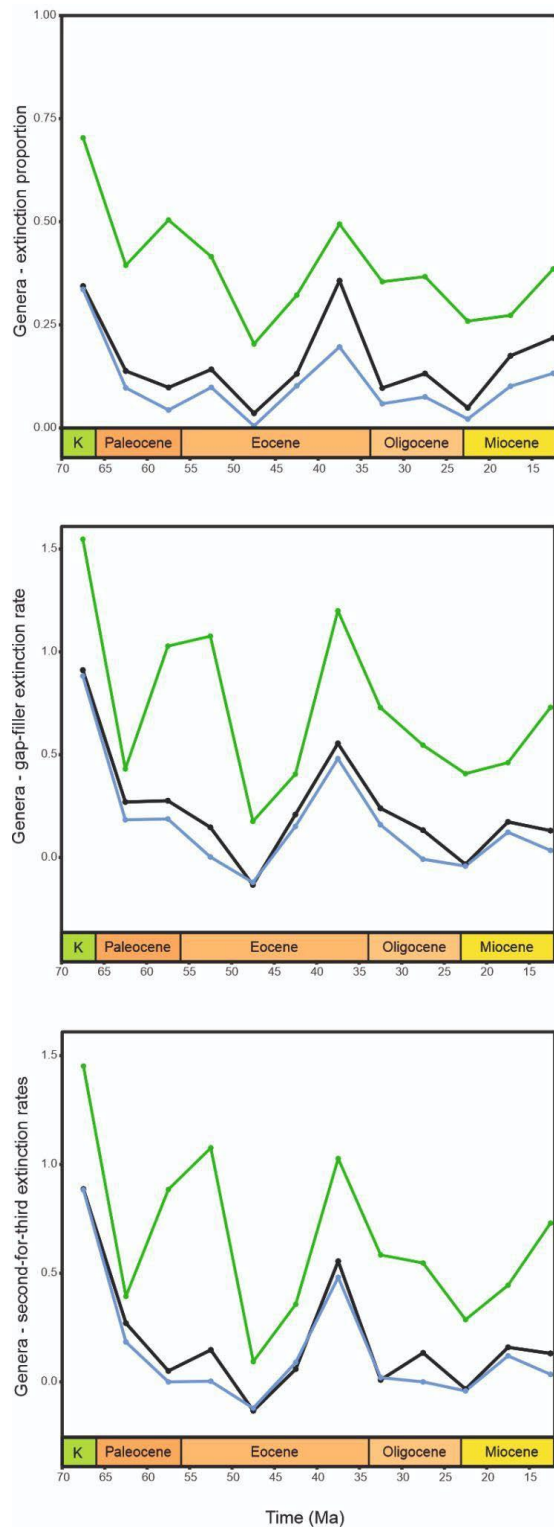
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FIGURE 2 - Proportional extinctions, gap-filler and second-for-third extinction rate using 5
my bins and genera from the Paleobiology Database (download April 2025) and the divDyn
R package (Kocsis *et al*., 2019). Points indicate the midpoint of each bin. Individual records
were assigned based on the midpoint of their potential date. Black indicates all genera, blue
genera from predominantly marine taxonomic groups and green mammals and reptiles.
Records missing genus information and singletons were not considered. Due to the
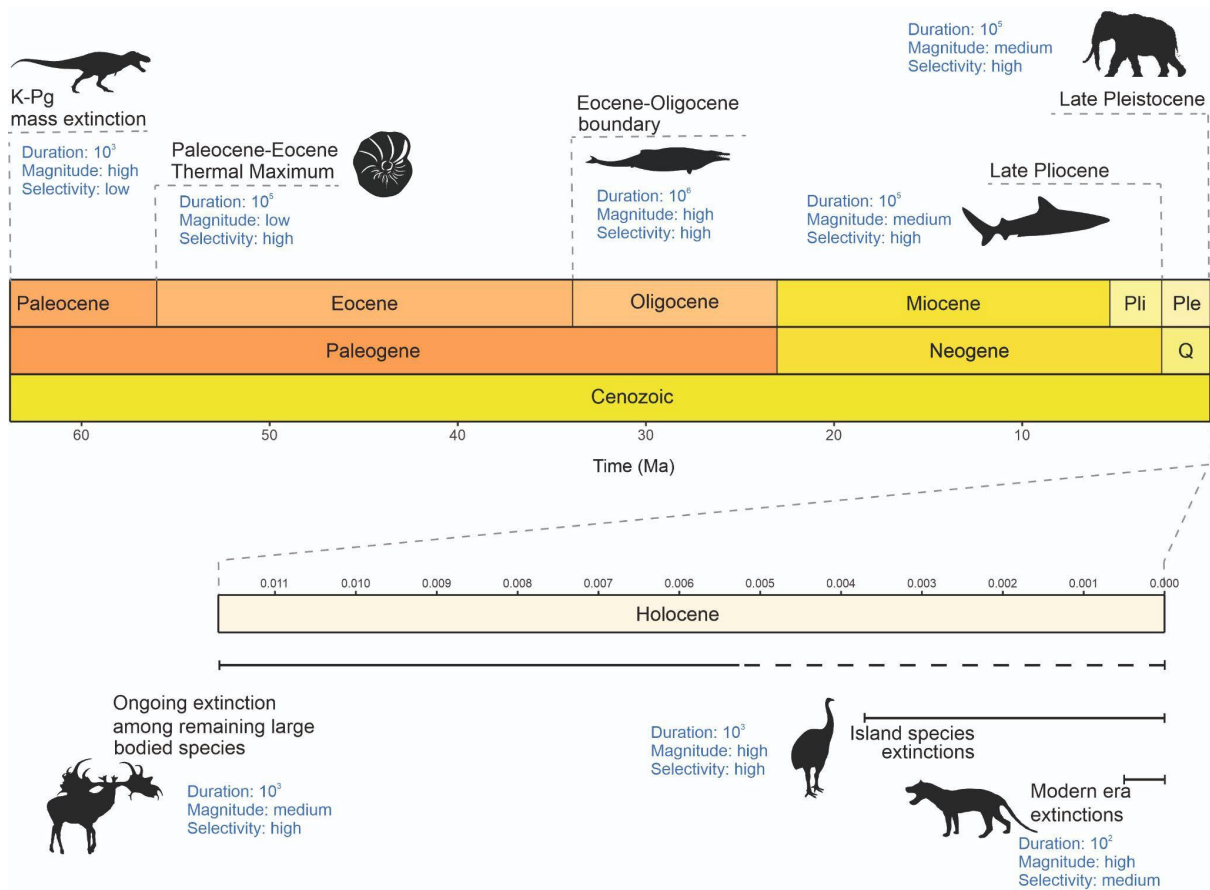resolution these can not be calculated for more recent bins.

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FIGURE 3 - A timeline of major Cenozoic extinction events. Produced using the R packages sepkoski (Jones 2022) and deeptime (Gearty 2024). Species silhouettes (phylopic.org contributors (M. Brea Lueiro, T.M. Keesey, S. Traver, J. Taylor) and Inês Martins) show single examples for illustrative purposes and are not intended to be comprehensive.

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1299   **Table 1** - Summary of magnitudes estimated for Cenozoic extinction events. These are
1300   based on different taxonomic and spatial data, and thus they are not necessarily all directly
1301   comparable.

Extinction event	Taxon	Geographic scope	Extinction magnitude	Reference
PETM	Deep sea benthic foraminifera	Local	33 to 65% (species)	Speijer et al., (2012)
Eocene-Oligocene	Marine animals	Global	15.6% (genera)	Bambach, (2006)
	Planktonic foraminifera	Regional	< 15% (species)	Keller, (1986)
	Endemic artiodactyls	Local	77% (species) 62% (genera)	Weppe et al., (2023)
Plio-Pleistocene	Marine animals	Global	Ranging by taxonomic group 0.5% to > 11% (genera)	Bambach, (2006)
	Marine megafauna	Global	36% (genera)	Pimiento et al., (2017)
	Molluscs	Regional	49% (species)	Pimiento et al., (2020)
	Corals	Regional	42% (genera)	van Woesik et al., (2012)
Anthropogenic	Mammals (since last interglacial)	Global	11% (genera)	Derived from Faurby et al., (2020)
	Mammalian megafauna (since last interglacial)	Global	43% (genera)	Derived from Faurby et al., (2020)
	Mammalian megafauna (Late Quaternary)	Regional	21% (Africa) to 88% (Australia) (genera) Continental median= 72%	Koch and Barnosky (2006)
	Birds (since last interglacial)	Global	12% (species)	Cooke et al., (2023)
	Pacific Island landbirds (Holocene)	Local	0 to 100% (species) Island median = 66.5%	Braje and Erlandson, (2013)

	Pacific Island land snails (since human occupation)	Regional	Approximately 50% (species)	Lydeard et al., (2004)
	Tetrapods (since 1500)	Global	1% (genera)	Ceballos and Ehrlich, (2023)

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