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Vertebrate biodiversity losses point to a sixth mass extinction

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Abstract The human race faces many global to local challenges in the near future. Among these are massive biodiversity losses. The 2012 IUCN/SSC Red List reported evaluations of ~56 % of all vertebrates. This included 97 % of amphibians, mammals, birds, cartilaginous fishes, and hagfishes. It also contained evaluations of ~50 % of lampreys, ~38 % of reptiles, and ~29 % of bony fishes. A cursory examination of extinction magnitudes does not immediately reveal the severity of current biodiversity losses because the extinctions we see today have happened in such a short time compared to earlier events in the fossil record. So, we still must ask how current losses of species compare to losses in mass extinctions from the geological past. The most recent and best understood mass extinction is the Cretaceous terminal extinction which ends at the Cretaceous–Paleogene (K–Pg) border, 65 MYA. This event had massive losses of biodiversity (~17 % of families, >50 % of genera, and >70 % of species) and exterminated the dinosaurs. Extinction estimates for non-dinosaurian vertebrates at the K–Pg boundary range from 36 to 43 %. However, there remains much uncertainty regarding the completeness, preservation rates, and extinction magnitudes of the different classes of vertebrates. Fuzzy arithmetic was used to compare recent vertebrate extinction reported in the 2012 IUCN/SSC Red List with biodiversity losses at the end of K–Pg. Comparisons followed 16 different approaches to data compilation and 288 separate calculations. I tabulated the number of extant and extinct species (extinct + extinct in the wild), extant island endemics, data deficient species, and so-called impaired species [species with IUCN/

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SSC Red List designations from vulnerable (VU) to critically endangered (CR)]. Species that went extinct since 1500 and since 1980 were tabulated. Vertebrate extinction moved forward 24–85 times faster since 1500 than during the Cretaceous mass extinction. The magnitude of extinction has exploded since 1980, with losses about 71–297 times larger than during the K–Pg event. If species identified by the IUCN/SSC as critically endangered through vulnerable, and those that are data deficient are assumed extinct by geological standards, then vertebrate extinction approaches 8900–18,500 times the magnitude during that mass extinction. These extreme values and the great speed with which vertebrate biodiversity is being decimated are comparable to the devastation of previous extinction events. If recent levels of extinction were to continue, the magnitude is sufficient to drive these groups extinct in less than a century.

Keywords Biodiversity · Mass extinction · Sixth mass extinction · Vertebrates · Fuzzy arithmetic · Fuzzy logic

Introduction

Biodiversity losses in our lifetime may be part of a sixth mass extinction (Barnosky et al. 2011a; Pimm et al. 2014; Wake and Vredenburg 2008). If this is a new event that began about 500 years ago (Pimm et al. 2014) or a continuation of the losses observed during the Pleistocene (Diamond 1989) remains to be seen. Species regularly appear and disappear throughout the fossil record and ~99 % of the 4 Billion species that evolved on our planet later became extinct (Novacek 2001). However, despite frequent claims, it is not the destiny of all species to become extinct, but rather to transition and diverge into newer forms (Diamond 1989).

Mass extinction is not especially selective in what groups go extinct, unlike background extinction which tends to be selective and proceed at a much lower magnitude (Jablonski 1986). Background extinction rates remain low when extinction is in balance with species origination, but if extinction sufficiently out-paces origination, mass extinction often follows (Hewzulla et al. 1999; Raup and Skepkoski 1982; Haggart 2002). In modern times, at least some origination is taking place as evidenced by the discovery of numerous cryptic species which appear proportionately (~1.1 % of vertebrates in 2007 were cryptic) across taxa and geography (Pfenniger and Swenck 2007). The number of undiscovered sister taxa are assuredly much larger than this; but, even this lower level provides to a vertebrate origination rate of 0.0012–1.1 originations/number of extant vertebrates/1 MY. Other more generalized estimates of modern origination range from 1 to 3 species of organisms per year. Depending on the taxon, origination can diverge from these values considerably (Gaurilets 2003).

A kill curve predicts that extinction episodes with losses of 10 % of species occur every million years (MY), 30 % every 10 MY, and 65 % every 100 MY (Raup 1991). Some studies suggest that the ancient mass extinctions ranged from 6 to 15 % lower than those levels (McKinney 1995), but they were clearly periods of calamity. Mass extinctions define the Ordovician, Devonian, Permian, Triassic, and Cretaceous Periods. Each occurred every 100 MY (Raup 1991) and spanned 0.05–2.76 MY (Figs. 1, 2).

Little is known about extinctions during the Precambrian Eon (542–4600 mya) and the early Cambrian Period (488.3–542 mya) (Jenkins 1989; Benton 1995). About 22–27 % of families (Brenchly 2007; Benton 2003), 57 % of genera, and 60–70 % of all species (Benton 1995, 2003) went extinct during the Ordovician–Silurian extinction (~444 mya). The Devonian–Carboniferous event (~359 mya) drove extinct ~32 % of biodiversity (19 % of families, 50 % of genera, and 70 % of species; Friedman and Sallan 2012; Benton 1995, 2003; Jablonski 1991) including ~44–88 % of vertebrates (Sallan and Coates 2010; Botha and Smith 2006; Retlack et al. 2003; Benton 2003), 67 % of tetrapods and 70 % of terrestrial vertebrates (Sahney and Benton 2008). The Permian–Triassic mass extinction (~251 mya) took between 0.05 and 9 MY depending on how the extinction event was defined (Payne and Clapham 2012; Yin et al. 2007; Huey and Ward 2005; Smith and Ward 2001; Bowring et al. 1999; Erwin 1990). It killed off 57 % of families, 83 % of genera, and 90–96 % of all species (Benton 2003). The Triassic–Jurassic mass extinction (~199 mya) eliminated 23 % of all families, 48 % of genera, and 70–75 % of all species (Benton 1995) and 45 % of terrestrial vertebrates (Olsen and Sues 1986) in 50,000 years (Yin et al. 2007) to ~0.5 MY (Erwin 1990).

The Cretaceous–Paleogene [K–Pg; previously known as the Cretaceous–Tertiary (*K–T*)] mass extinction is the most recent mass extinction, taking place 65 MY ago, and the best understood. Still, there is much uncertainty about its duration (Fig. 1) and severity (Suppl. Table 1). The border between the end of the Cretaceous and the beginning of the Paleogene Periods is known as the K–Pg boundary and shows massive changes in vertebrate and invertebrate diversity. This extinction lasted 0.5–2.75 MY (Briggs 1991; Hallam and Wignall 1997; Yin et al. 2007; Erwin 1990; Bowring et al. 1999; Huey and Ward 2005; Payne and Clapham 2012; Jablonski 1994; Erwin et al. 2002; Li and Keller 1998; Costello et al. 2013) and exterminated the dinosaurs (Jablonski 1991; Krug et al. 2009), although survival into the Paleocene Epoch of a few dinosaurs is under debate (Fassett et al. 2012). The Cretaceous terminal extinction eliminated 17 % of families, 50 % of genera, and 75 %

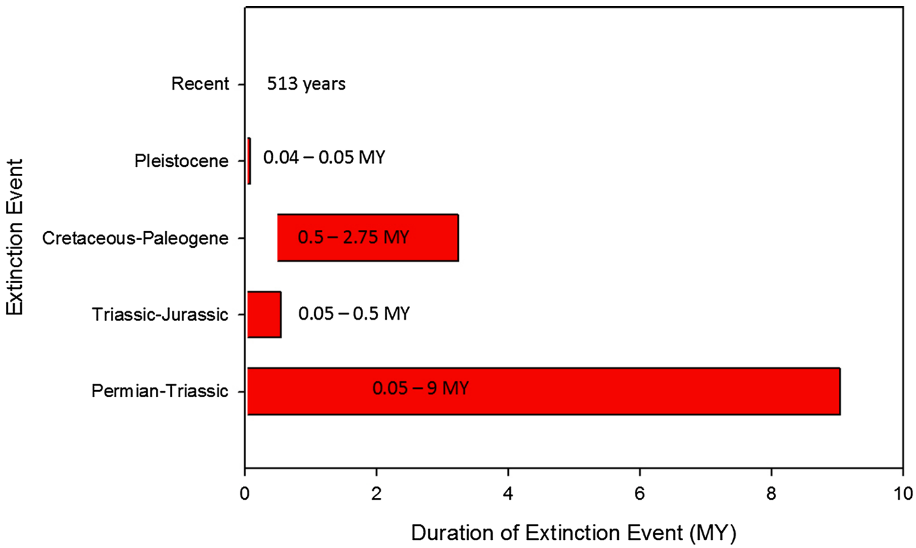

Fig. 1 Duration of the three most recent great extinctions compared to the duration of the Pleistocene megafauna event and post-1500 recent extinction

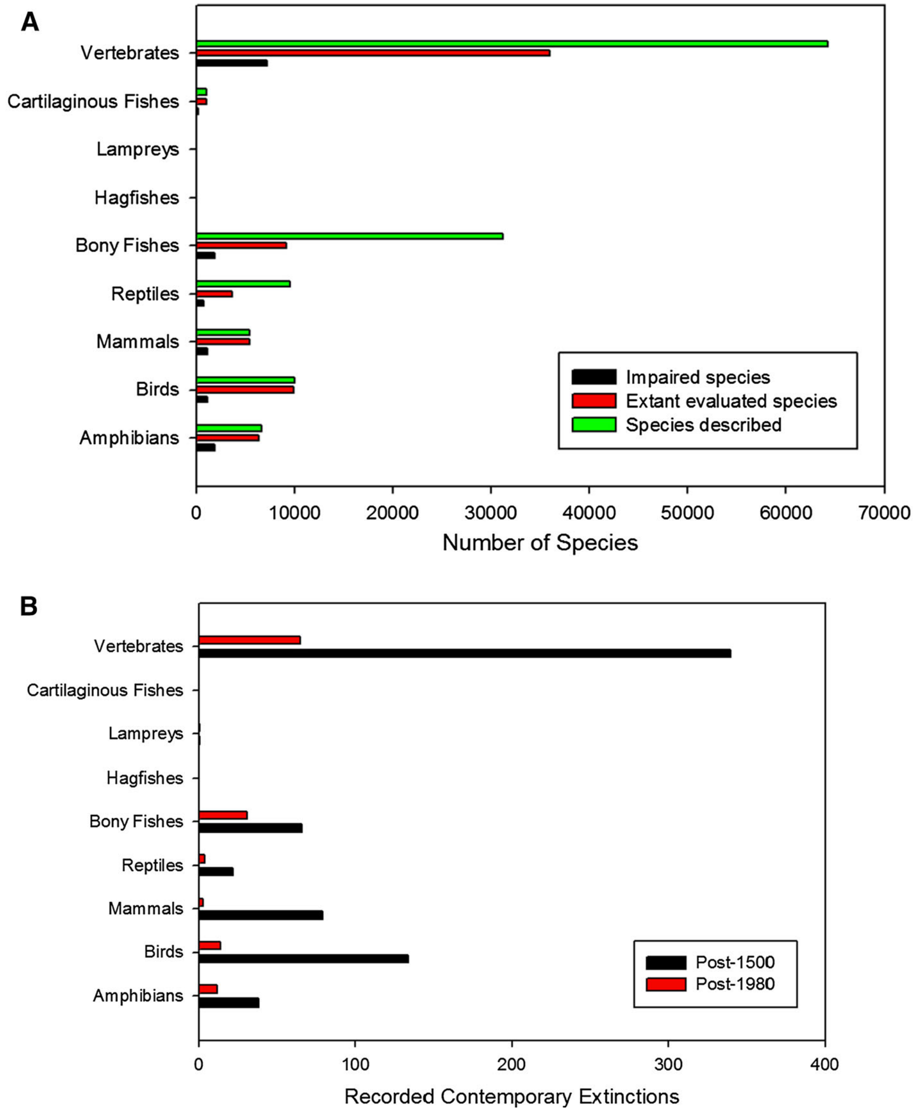

Fig. 2 Number of species that **a** are described, received an IUCN Red List evaluation, are impaired and **b** those that were recorded as extinct since 1500 and since 1980

of all species (Raup and Skepkoski 1982) including 36–45 % of non-dinosaur vertebrates (Suppl. Table 1).

Among the many explanations posed for these previous five mass extinctions, only a small number of factors are the sort that could cause the global-scale environmental perturbations leading to these disappearances: bolide impacts, volcanism, climatic cooling, marine regression and marine transgression with the spread of anoxic bottom waters, and continental drift (Hallam 1998; Milner 1998). Unlike those previous mass extinctions, the losses that led many to ask if we are in a sixth mass extinction are largely caused directly and indirectly by the organism, *Homo sapiens* (Diamond 1989).

Vertebrates comprise ~3.4 % of the ~1.9 million described, extant species on Earth (Suppl. Table 2; Fig. 2). Of these vertebrates, ~56 % of their International Union for Conservation of Nature (IUCN) Species Survival Commission (SSC) evaluations was complete (IUCN/SSC Red List 2012). Over 97 % of known amphibians, birds, mammals, hagfishes, and cartilaginous fishes had published IUCN/SSC evaluations. Of the remaining vertebrate classes, about half of the lampreys, 29 % of the bony fishes, and 38 % of the reptiles were published. The large proportion of vertebrates with IUCN/SSC evaluations provided sufficient numbers to make basic comparisons of current biodiversity losses to the mass extinctions of the past (Suppl. Table 2; Fig. 2).

Previous studies comparing recent vertebrate extinctions to those in the fossil record exist. One (Pimm et al. 1995) extensive multi-taxon study is still very important. The avian component was revisited in 2006 (Pimm et al. 2006) and predicted 1500 E/MSY (E/MSY = extinctions per million species per year using point estimates), and a new installment (Pimm et al. 2014) updated this even further. It suggested current extinction magnitude is 1000 times background. A recent comprehensive study (Barnosky et al. 2011a) compared current extinction rates to ancient ones using interval analysis. It reported biodiversity losses comparable to the great extinctions. Three earlier studies compared modern biodiversity losses to paleontological extinctions. One with mammals (Regan et al. 2001) and another with amphibians (McCallum 2007) used fuzzy arithmetic, and a third study used molecular clocks with amphibians (Roelants et al. 2007). Each revealed that current extinction magnitudes of amphibians and mammals are not in line with background extinction and more closely resemble magnitudes from previous mass extinctions. Although these previous studies are landmark papers of high importance warranting widespread attention, each leaves missing gaps due to method selection or limited taxonomic scope (see supplemental discussion).

Herein, fuzzy arithmetic is applied to data from the 2012 IUCN Red List (IUCN/SSC Red List 2012, Suppl. Table 2) to provide comprehensive, quantitative comparisons of modern vertebrate extinction to the range of extinction estimates for vertebrates at the end of the Cretaceous Period (Suppl. Table 1; Archibald and Bryant 1990; Azuma and Currie 2000; Belohlavek and Klir 2011; Benton 1998; Benton et al. 2000; Capetta 1987; Chiappe 1995; Clarke et al. 2005; Clemmens 1986; Cooper and Penny 1997; Darbra and Casal 2009; Darba et al. 2008; Fara and Benton 2000; Fitch and Ayala 1995; Flynn et al. 1999; Fountaine et al. 2005; Global Biodiversity Outlook 3, 2010; Global Biodiversity Outlook 2, 2006; Hou et al. 1996; Li 2009; Longrich et al. 2011, 2012; MacLeod et al. 1997; Matsukawa et al. 1997; Patterson 1993; Raup 1994; Robertson et al. 2004; Sepkoski 1981) in an attempt to fill aforementioned missing gaps and confront recent findings (Barnosky et al. 2011a; Pimm et al. 2014; Wake and Vredenburg 2008) that current biodiversity losses may be a sixth mass extinction. I questioned if recent biodiversity losses are in line with a mass extinction. I predicted that if they are comparable, then the fraction of species that went extinct in recent times should be proportional to what went extinct at K–Pg; but, if recent extinctions are proportionately lower than K–Pg, we would lack evidence that current biodiversity losses resemble a mass extinction.

Materials and methods

All calculations involved constructing fuzzy numbers that encompassed the available data where values outside of the interval range encompassed by the fuzzy number were largely not possible, those where membership = 1 were possible, and those with memberships ranging from zero to one were marginally possible (Suppl. Fig. 1). The basis for Fuzzy Arithmetic is a consistent axiomatic system as useful as, but different from probability theory (Ferson et al. 1995). This method rates data (x-axis) by its degree of possibility referred to as membership values (y-axis) where y = 0 = no possibility and y = 1 = the highest possibility. Data are graphically expressed as triangles, trapezoids, or similar shapes that have curvilinear legs connecting y = 0 to y = 1. I used triangular and trapezoidal graphical representations. With a triangular fuzzy number, the data point at the apex would be the only value that is 100 % possible. The segments forming the sides represent the decreasing possibility of each x-value as x diverges from y = 1. All x-values where y = 0, located to either side of the base of this triangle are minimally or not possible. If the graphical representation were a trapezoid, the interpretation would be similar except that a series of equally possible values exist on the upper base where y = 1. If we have a fuzzy set [2, 7, 8, 10] then we interpret that to mean the segment between seven and eight are 100 % possible, whereas values of two and ten are bordering on impossible. The values from 2 to 7 and from 8 to 10 have possibilities >0 and <100 %. Fuzzy methods are well supported for dealing with uncertainty in data sets (Ferson 2008; Abrahamsson 2002; Fowle and Dearfield 2000; U.S. EPA 1992, 1998; Zadeh 1990).

I used fuzzy arithmetic to compare previously published estimates (Suppl. Table 2; Fig. 3) of vertebrate extinction during the K–Pg extinction to post-1500 AD and post-1980 AD extinction data and taxonomic definitions in the IUCN Red List (IUCN/SSC Red List 2012). Then, I used these results to calculate the time required for these extinction magnitudes to completely drive each group to extinction if they were sustained (Kitchell and Hoffman 1991; Endler 1986; Cooper 1984). Computations used tenets of Fuzzy Arithmetic (Regan et al. 2001) and adaptations of previously described standard equations (Suppl. Table 3) (Regan et al. 2001; McCallum 2007).

I made these calculations for eight sets of basic data, combining all cases with and without islands species, two time frames (after 1500 and after 1800) and including impaired species and data deficient (DD) species as potentially "extinct" or not extinct. I tabulated vertebrate species occurring on islands and continents from each conservation category on the IUCN Red List (Suppl. Table 2; Fig. 2). All Extinct (EX) and Extinct-in-the-wild (EW) species were combined as extinct. This was used to provide a point estimate of recent extinctions for the periods 1500 AD to present and 1980 AD to present for comparison to the Cretaceous mass extinction. Then, the EX and EW were combined with vertebrate species from islands or continents that were classified as critically endangered (CR), endangered (EN), or vulnerable (VU) to account for Signor–Lipps effect (Signor and Lipps 1982). I performed calculations including and excluding DD species as extinct because a previous study (Barnosky et al. 2011a) included them among the impaired groups due to their small populations or ranges that suggest a high risk of extinction (Barnosky et al. 2011a).

Species listed by the IUCN as CR, EN, or VU were termed as "impaired species" in this study (IUCN/SSC Red List 2012). This latter estimate (Suppl. Table 1) where extinct and impaired species are combined represented the "modern extinctions by fossil record standards." From a paleontological perspective, most if not all impaired and data deficient species are already extinct (Barnosky et al. 2011a; McCallum 2007; Pimm 2002) because they are generally rare (Wignall and Benton 1999) with low population densities and limited distributions (Signor and Lipps 1982; Belovsky et al. 1999; Henle et al. 2004), and classically they are likely "dead clades walking" (Jablonski 2002). The patchiness and incomplete nature of the fossil record provide fewer opportunities for preservation as problems with original density and distribution become more pronounced (Alroy 2014;

Benton et al. 2011; Foote 1997; Nowak et al. 2000; Signor and Lipps 1982). Despite this, the fossil record remains adequate to make the comparisons herein (Signor and Lipps 1982). Impaired species are also more likely to go extinct in the short-term especially if additional stressors arise, and can be significant components of recent and future biodiversity losses (Barnosky et al. 2011a; Pimm et al. 2006).

I constructed Fuzzy Estimates (Suppl. Fig. 1) of the post-1500 and post-1980 extinction for each taxon by setting the point estimate (x), where y = 1, and then setting an upper and lower bound to this estimate = x ± 10 %, where membership = 0. The number of species described and evaluated (Suppl. Table 2) was combined to form a Fuzzy Estimate of total extant species richness for each taxon (Suppl. Table 2). If IUCN evaluations existed for all described species of a vertebrate class, then the Fuzzy Estimate used the number evaluated ±10 % as the upper and lower boundaries. If there remained species to be evaluated in a given taxon, then I set the number evaluated as the lower bound of membership = 1, and the number described as the upper bound of membership = 1, with the upper and lower boundaries of the fuzzy set (where membership = 0) equal to the number of species evaluated −10 % and the number of species described +10 % following Regan et al. (2002; 2001). This was done for the subphylum Vertebrata and each class of vertebrates. For example, 38 amphibians went extinct since 1500, and 38 × 0.1 = 34 and 38 × 1.1 = 42, so the fuzzy estimate for amphibian extinctions = [36, 38, 42]. Here the highest membership (membership = 1) belongs to 38 and is most possible, but the bounds of this fuzzy set (36 and 42) each have membership = 0 and are not possible, nor is possible any value <36 or >42.

I obtained from the literature the K–Pg extinction estimates ($R_{K\text{–}Pg}$) and completedness indices (see Kriwet and Benton 2004; Bryant 1989), either relative (RCI) or simple (SCM), for each taxon (Suppl. Table 1; Suppl. Fig. 2). I converted K–Pg extinction estimates into fuzzy numbers by setting the lowest available estimate as the minimum boundary, the highest available estimate as the upper boundary, and the intermediate value as membership = 1. If there were only two values available, I created a trapezoidal fuzzy set in which both values had membership = 1, and then set the upper and lower boundaries ±10 % of the higher or lower point estimate respectively (For some groups a boundary of 20 % or more might be more accurate, however, we felt a more conservative 10 % would provide for minimal inflation of outcomes). Where more than three estimates were available, I set the lowest and highest estimates as membership = 0. Then I set the second lowest and second highest values as membership = 1. This caused all remaining available estimates to occur on the upper surface of the trapezoid where they are fully possible. I adapted a series of standard equations (Suppl. Table 3) to make calculations (Suppl. Table 4) for comparing and evaluating extinction and biodiversity declines examined in this study.

Interpretation of fuzzy sets (Suppl. Fig. 1) resulting from comparisons of current extinction magnitude to that at K–Pg followed that values within a fuzzy set that were negative were estimates that ranged lower than extinction magnitude at K–Pg. A value of zero would be an extinction magnitude similar to that at K–Pg, and a positive value is one that exceeds extinction at K–Pg. So, the fuzzy set [−100, 0, 100] represents an extinction magnitude ranging from 100 times less than K–Pg, to 100 times greater than K–Pg with the best estimate (0) equal to K–Pg The value zero is possible (membership = 1). Whereas, all values ranging between −100–0 and 0–100 (not including zero) are marginally possible, with decreasing possibility as membership moves from 1→0. This provided us with the power of interval analysis used by Barnosky et al. (2011a, b) and a manner of evaluating the relative importance of values within the interval estimate, which that study lacked.

Table 1 Forecasts of future vertebrate losses based on current trends (numbers in brackets [] are fuzzy sets)

	Amphibians	Birds	Mammals	Reptiles	Bony Fishes	Hagfishes	Lampreys	Cartilaginous fishes	Vertebrates
(A)	[7×10^{-8}, 6×10^{-7}, 7×10^{-7}]	[1×10^{-7}, 9×10^{-7}, 1×10^{-6}]	[6×10^{-8}, 5×10^{-7}, 6×10^{-7}]	[4×10^{-8}, 3×10^{-7}, 1×10^{-6}]	[1×10^{-7}, 8×10^{-7} 3×10^{-6}]	[9×10^{-10}, 7×10^{-9}, 8×10^{-9}]	[2×10^{-10}, 2×10^{-9}, 3×10^{-9}, 4×10^{-9}]	[1.3×10^{-8}, 1.0×10^{-7}, 1.2×10^{-7}]	[4.2×10^{-7}, 3.3×10^{-6}, 9×10^{-6}, 7.2×10^{-6}]
(B)	100 % (6671)	100 % (10,064)	100 % (5501)	100 % (9547)	100 % (31,193)	? % (76)	100 % (38)	? % (1093)	100 % (64,283)
(C)	[66277, 74074, 81871]	[235867, 261209, 286550]	[138402, 153996, 169591]	[38986, 42885, 46784]	[115010, 128655, 142300]	0	[1754, 1949, 2144]	0	[596491, 662768, 729,045]
(D)	[333333, 363636, 393939]	[393939, 424242, 454546]	[81818, 90909, 100000]	[109091, 121212, 133333]	[848485, 939394, 1030304]	n/a	[27273, 30303, 33333]	n/a	[1787878, 1969696, 2181819]
(E)	[70025, 85995, 90959, 110718]	[31188, 38016, 38529, 46933]	[29194, 35722, 43721]	[70473, 85415, 222619, 269376]	[58004, 71284, 242455, 298340]	n/a	[7928, 9747, 19494, 23940]	n/a	[44388, 54253, 96992, 118545]
(F)	[14553, 17518, 18345, 21021]	[19661, 23406, 23772, 28101]	[49510, 60511, 73957]	[24727, 30220, 78763, 96268]	[8011, 9763, 33205, 40439]	n/a	[510, 627, 1254, 1540]	n/a	[14832, 18255, 32636, 39550]
(G)	[1358, 1660, 1738, 2124]	[3175, 3880, 3932, 4804]	[1894, 2315, 2830]	[1867, 2280, 5944, 7261]	[1921, 2349, 7989, 9768]	[3354, 4104, 4587, 5670]	[1982, 2437, 4874, 5985]	[2518, 3072, 3089, 3771]	[1994, 2438, 4358, 5327]
(I)	[89, 108, 113,138]	[224, 275, 278, 340]	[130, 159, 194]	[123, 150, 391, 478]	[126, 154, 523, 639]	[3354, 4104, 4587, 5670]	[128, 157, 314, 385]	[162, 198, 199, 243]	[133, 163, 291, 356]
(J)	[70, 90, 95, 120]	[110, 160, 164, 227]	[86, 115, 150]	[90, 118, 360, 447]	[90, 118, 487, 604]	[227, 279, 342	[70, 95, 302, 390]	[162, 198, 199, 243]	[86, 116, 244, 309]
(K)	[1775, 1977, 2072, 2285]	[21884, 25924, 26408, 31117]	[2865, 3212, 3216, 3570]	[2024, 2254, 5883, 6487]	[1876, 2091, 7114, 7849]	[997, 1114, 1560, 1724]	[1939, 2167, 5571, 6157]	[1005, 1116, 1118, 1230]	[2602, 2906, 5197, 5747]
(L)	[1401, 1636, 1732, 1978]	[21971, 38606, 40028, 60033]	[1970, 2425, 2428, 2897]	[1521, 1808, 5516, 6190]	[1350, 1611, 6639, 7423]	[997, 1114, 1560, 1724]	[875, 1112, 4104, 4814]	[1005, 1116, 1118, 1230]	[1720, 2121, 4476, 5141]

Table 1 continued

	Amphibians	Birds	Mammals	Reptiles	Bony Fishes	Hagfishes	Lampreys	Cartilaginous fishes	Vertebrates
(M)	[116, 129, 135, 149]	[3805, 4283, 4399 4903]	[204, 226, 249]	[133, 148, 387, 426]	[123, 137, 465, 512]	[64, 72, 100, 112]	[100, 114, 279, 315]	[65, 72, 79]	[176, 195, 349, 385]
(N)	[92, 107, 113, 129]	[2041, 2773, 2880, 3674]	[135, 164, 193]	[99, 117, 356, 399]	[88, 105, 434, 484]	[64, 72, 100, 111]	[56, 72, 264, 310]	[65, 72, 79]	[113, 139, 293, 334]
(O)	[778, 912, 955, 1112]	[3043, 3703 3756, 4567]	[1187, 1398, 1399, 1638]	[985, 1149, 2996, 3470]	[965, 1124, 3822, 4417]	[768, 876, 1164, 1322]	[980, 1147, 2599, 3035]	[718, 819, 821, 927]	[1158, 1359, 2430, 2831]
(P)	[614, 755, 798, 962]	[1595, 2352, 2409, 3340]	[798, 1031, 1031, 1295]	[732, 912, 2779, 3276]	[694, 866, 3566, 4175]	[769, 876, 1164, 1322]	[568, 741, 2345, 2845]	[718, 819, 821, 927]	[755, 977, 2061, 2492]
(Q)	[50, 59, 62, 72]	[215, 261, 265 322]	[79, 93, 94, 109]	[63, 73, 248, 286]	[49, 56, 75, 85]	[63 74, 167.2, 195]	[46, 53, 60]	[46, 53, 60]	[76, 89, 160, 186]
(R)	[40, 49, 52, 62]	[107, 156, 160, 220]	[53, 68, 85]	[47, 59, 179, 211]	[45, 56, 231, 271]	[49, 56, 75, 85]	[37, 48, 151, 183]	[46, 53, 60]	[49, 63, 134, 161]

A: Extinctions (*N*) expected since 1500 AD based on marine invertebrate background extinction, B: % extinction expected in 1 MY (N of species), C: extinctions per million years predicted based on -Post-1500 magnitude*, D: extinctions per million years predicted based on Post-1980 magnitude*, E: Years until total extinction based on post-1500 magnitude, F: -Years until total extinction based on post-1980 magnitude, G: Years until total extinction based on post-1500 extinctions + impaired species, H: -Years until total extinction based on post-1980 extinction including impaired species, I: Years until total extinction based on post-1980 extinction including impaired species but excluding island endemics. J: Years until total extinction for each taxon based on post-1500 extinction rate including data deficient species as extinct, K: Years until total extinction for each taxon based on post-1500 extinction rate excluding island species and including data deficient species as extinct, L: Years until total extinction for each taxon based on post-1980 extinction rate with data deficient species included as extinct, M: Years until total extinction for each taxon based on post-1980 extinction rate excluding island species and including data deficient species as extinct, N: Years until total extinction for each taxon based on post-1500 extinction including impaired species, O: Years until total extinction for each taxon based on post-1500 extinction including impaired species but excluding island species, P: Years until total extinction for each taxon based on post-1980 extinction rate including impaired species and data efficient species as extinct, Q: Years until total extinction for each taxon based on post-1980 extinction rate including impaired species but excluding island species

Table 2 Comparisons of recent extinction and impairment rates to extinction rates at K–Pg expressed as fuzzy Sets

Scenario	Amphibians	Birds	Mammals	Reptiles	Bony Fishes	Hagfishes	Lampreys	Cartilaginous fishes	Vertebrates
A, C, F	[13, 34, 35, 256]	[31, 63, 78, 544]	[42, 81, 89, 186]	[4, 6113, 198]	[5, 9, 46, 290]	n/a	[30, 70, 643, 1246	n/a	[7, 24, 85, 174]
A, C, G	[632, 1462, 1532, 10832]	[47, 92, 114, 777]	[238, 455, 497,3911]	[154, 219, 4296, 6890]	[190, 304, 1579, 8957]	n/a	[145, 316, 3540, 6346]	n/a	[155, 447, 1592, 2969]
A, D, F	[15, 40, 43, 357]	[−84, 11, 14, 297]	[24, 61, 67,177]	[0, 1, 26, 90]	[5, 9, 58, 392]	n/a	[15, 42, 1411, 3082]	n/a	[3, 14, 58, 156]
A, D, G	[730, 1750, 1852, 13727]	[55, 129, 161, 1704]	[293, 602, 658, 5688]	[161, 233, 5357, 9173]	[202, 26, 2049, 12451]	[670, 1676, 11130, 25050]	[146, 334, 5643, 11751]	[578, 1223, 5627, 9847]	[176, 520, 2183, 4276]
A, C, E, F	[679, 1744, 1826, 14536]	[304, 620, 763, 5346]	[654, 1253, 1368, 2863]	[285, 416, 1229, 7471]	[153, 271, 1406, 8745]	[124, 298, 1528, 2975]	[96, 281, 2574, 5779]	[189, 443, 2042, 3925]	[167, 534, 1899, 3873]
A, C, E, G	[1299, 3172, 3323, 24720]	[47, 92, 114, 777]	[519, 1045, 1141, 9442]	[288, 429, 8429, 14163]	[338, 566, 2938, 17412]	[545, 1194, 7079, 12748]	[211, 526, 5470, 10878]	[768, 1668, 7657, 13752]	[313, 957, 3405, 6667]
A, D, E, F	[621, 1728, 1828, 15836]	[167, 523, 650, 8013]	[470, 1104, 1205, 3041]	[82, 150, 3449, 7130]	[138, 255, 1604, 10954]	[−713, 68, 940, 3567]	[49, 208, 3292, 9054]	[70, 417, 1978, 9125]	[123, 450, 1978, 9125]
A, D, E, G	[1336, 3438, 3637, 28805]	[235, 637, 793, 9412]	[213, 603, 658, 7206]	[243, 382, 8779, 16214]	[334, 571, 3594, 23012]	[670, 1813, 11757, 27873]	[180, 500, 7525, 17723]	[1331, 4028, 18523, 60116]	[298, 956, 4016, 8474]
B, C, F	[66, 165, 173, 1356]	[52, 103, 127, 863]	[25, 48, 52, 110]	[10, 16, 320, 564]	[37, 65, 338, 2097]	n/a	[462, 1092, 10004, 19377]	n/a	[22, 71, 253, 521]
B, C, G	[24743, 52671, 55194, 220136]	[435, 684, 854, 4548]	[9124, 15364, 16074, 81885]	[3425, 4715, 87011, 130278]	[1982, 2531, 13167, 61682]	[670, 1676, 11130, 25050]	[3729, 6629, 75250, 113746]	[9853, 23173, 69658, 139068]	[297, 955, 4015, 8474]
B, D, F	[72, 189, 218, 1784]	[25,75, 94,923]	[26, 55, 84, 190]	[0.9, 4, 102, 296]	[38, 69, 446, 2959]	n/a	[233, 648, 21932, 47914]	n/a	[21, 71, 297, 696]
B, D, G	[11198, 26784, 28330, 215113]	[449, 947, 1193, 9170]	[5173, 9219, 38457, 66620]	[2506, 3610, 82970, 141502]	[3089, 4986 31388, 190341]	[10422, 29145, 187151, 41650]	[2702, 7647, 115491, 260250]	[21599, 65641, 301267, 962473]	[7445, 17569, 73804, 138293]

Table 2 continued

Scenario	Amphibians	Birds	Mammals	Reptiles	Bony Fishes	Hagfishes	Lampreys	Cartilaginous fishes	Vertebrates
B, C, E, F	[10433, 26746, 28010, 222939]	[4301, 8761, 10783, 75511]	[9530, 18262, 19934, 41726]	[2091, 3290, 64577, 113633]	[2338, 4133, 21468, 133533]	[1926, 4640, 23760, 46241]	[1489, 4367, 40017, 89840]	[2934, 6889, 31738, 61019]	[2497, 7994, 28444, 58021]
B, C, E, G	[20056, 48956, 51284, 391380]	[4523, 9213, 11348, 79102]	[19687, 35928, 37556, 68261]	[4657, 6596, 129635, 207472]	[5220, 8718, 45298, 268250]	[8370, 18287, 111298, 199937]	[3338, 8734, 80035, 167348]	[11928, 25924, 119128, 214008]	[3007, 8896, 17539, 54201]
B, D, E, F	[9502, 26471, 27999, 242605]	[2816, 7979, 9916, 120988]	[6966, 16274, 17788, 44711]	[1278, 2322, 53305,109746]	[2102, 3888, 24469, 167138]	[−11091, 1064, 14622, 55457]	[758, 3241, 51176, 140749]	[1094, 6486, 30741, 141852]	[1887, 6855, 28793, 69225]
B, D, E, G	[6029, 9487, 10035, 129875]	[1997, 5330, 5462, 58482]	[10133, 21324, 21352, 49642]	[2134, 3130, 71899, 115751]	[5645, 10720, 44168, 322264]	[9436, 33670, 147630, 475760]	[2014, 6200, 142403, 40868]	[221120, 74737, 225027, 836980]	[2566, 7932, 18464, 63324]

Key to scenarios column: number of times the (*A* post-1500, *B* post-1980) extinction rate exceeds R_{k-Pg} when (*C* ignoring effects of island endemics, *D* excluding island endemics, *E* including impaired species as extinct by geologic standards, *F* excluding data deficient species, *G* including data deficient species

Results

Vertebrates

Of the 64,283 species of vertebrates listed in the 2012 IUCN/SSC Red List, 0.5 % went extinct sometime since 1500 and roughly 20 % of extinct vertebrates went extinct since 1980 (Suppl. Table 2). Impaired (11.2 %) and data deficient (9.3 %) species raise the expected magnitude of extinction by geologic standards to 21.1 % since 1500. Roughly 98 % of the extinct, impaired and data deficient species would have disappeared from the fossil record since 1980.

The extinction magnitude observed since 1500 is at least 15–60 times the magnitude observed during the K–Pg event (Table 2). Addition of impaired and data deficient species increases the extinction magnitude to at least 956–4016 times K–Pg. None of the 16 approaches gave results below that observed at K–Pg, let alone levels representative of background extinction.

If the extinction rate moving into the future (Table 1) is no larger than the magnitude of species that already went extinct in recent times, then complete extinction of all vertebrates might occur in 18,000–97,000 years, depending on if the post-1980 or post-1500 extinction magnitudes are used. However, the complete extinction by geologic standards could be in as little as 60–2000 years.

Amphibians

Of the 6671 species of amphibians listed in the 2012 IUCN/SSC Red List, 0.6 % went extinct sometime since 1500 and roughly 31 % of these extinct amphibians disappeared since 1980 (Suppl. Table 2). Impaired (28.9 %) and data deficient (24.2 %) amphibians raise the expected magnitude of extinction by geologic standards to 53.7 % since 1500. Roughly 99.2 % of extinct, impaired, and data deficient species would have disappeared from the fossil record since 1980.

The magnitude of amphibian extinctions observed since 1500 is at least 34–43 times the magnitude observed during the K–Pg mass extinction (Table 2). Addition of impaired and data deficient species increases extinction to at least 3172–3673 times K–Pg.

If the extinction rate moving into the future (Table 1) is no larger than the magnitude of species that have already gone extinct during recent times, then complete extinction of all amphibians might occur in 17,000–91,000 years, depending on if the post-1980 or post-1500 extinction magnitudes are used. However, the complete extinction by geologic standards could take 49–800 years. None of the 16 approaches gave results below that observed at K–Pg, let alone levels representative of background extinction.

Birds

Of the 10,064 species of birds listed in the 2012 IUCN/SSC Red List, 1.3 % went extinct sometime since 1500 but only 10.4 % of these extinct birds disappeared since 1980 (Suppl. Table 2). Impaired (11.7 %) and data deficient (0.6 %) birds raise the expected magnitude of extinction by geologic standards to 13.7 % since 1500. Roughly 91.3 % of extinct, impaired, and data deficient birds would have disappeared from the fossil record since 1980.

The magnitude of avian extinctions observed since 1500 is at least 11–78 times the magnitude observed during the K–Pg mass extinction (Table 2). Inclusion of impaired and data deficient species increases post-1500 extinction to at least 92–793 times K–Pg.

If the extinction rate moving into the future (Table 1) remains no larger than the magnitude of avian species that have already gone extinct during recent times, then complete extinction of all birds might occur in 23,400–38,500 years, depending on if the post-1980 or post-1500 extinction magnitudes are used. However, the complete extinction by geologic standards could take 156–2400 years. None of the 16 approaches gave results below that observed at K–Pg, let alone levels representative of background extinction.

Mammals

Of the 5501 species of mammals listed in the 2012 IUCN/SSC Red List, 1.4 % went extinct sometime since 1500 but only 3.8 % of these extinct mammals disappeared since 1980 (Suppl. Table 2). Impaired (11.7 %) and data deficient (0.6 %) birds raise the expected magnitude of extinction by geologic standards to 13.7 % since 1500. Roughly 96.2 % of extinct, impaired, and data deficient mammals would have disappeared from the fossil record since 1980.

The magnitude of mammalian extinctions observed since 1500 is at least 11–78 times the magnitude observed during the K–Pg mass extinction (Table 2). Inclusion of impaired and data deficient species increases post-1500 extinction to at least 603–1203 times K–Pg.

If the extinction rate moving into the future (Table 1) is no larger than the magnitude of mammalian species that have already gone extinct during recent times, then complete extinction of all mammals might occur in 23,400–38,500 years, depending on if the post-1980 or post-1500 extinction magnitudes are used. However, the complete extinction by geologic standards could take 68–1000 years. None of the 16 approaches gave results below that observed at K–Pg, let alone levels representative of background extinction.

Reptiles

Of the 9547 species of reptiles listed in the 2012 IUCN/SSC Red List, 0.2 % went extinct sometime since 1500 and 18.2 % of these extinct reptiles disappeared since 1980 (Suppl. Table 2). Impaired (8.4 %) and data deficient (8.5 %) reptiles raise the expected magnitude of extinction by geologic standards to 17.3 % since 1500. Roughly 97.7 % of extinct, impaired, and data deficient reptiles would have disappeared from the fossil record since 1980.

The magnitude of reptile extinctions observed since 1500 is at least 1–113 times the magnitude observed during the K–Pg mass extinction (Table 2). Inclusion of impaired and data deficient species increases extinction to at least 382–8779 times K–Pg.

If the extinction rate moving into the future (Table 1) is no larger than the magnitude of reptilian species that have already gone extinct during recent times, then complete extinction of all reptiles might occur in 30,200–222,600 years, depending on if the post-1980 or post-1500 extinction magnitudes are used. However, the complete extinction by geologic standards could take 59–2800 years.

Bony fishes

Of the 31,193 species of bony fishes listed in the 2012 IUCN/SSC Red List, 0.2 % went extinct sometime since 1500 and 47.0 % of these extinct fishes disappeared since 1980 (Suppl. Table 2). Impaired (6.2 %) and data deficient (7.0 %) bony fishes raise the expected magnitude of extinction by geologic standards to 13.1 % since 1500. Roughly 99.2 % of extinct, impaired, and data deficient bony fishes would have disappeared from the fossil record since 1980.

The magnitude of bony fish extinctions observed since 1500 is at least 9–58 times the magnitude observed during the K–Pg mass extinction (Table 2). Inclusion of impaired and data deficient species increases extinction to at least 566–3594 times K–Pg.

If the extinction rate moving into the future (Table 1) is no larger than the magnitude of bony fish species that have already gone extinct during recent times, then complete extinction of all bony fishes might occur in 9763–242,455 years, depending on if the post-1980 or post-1500 extinction magnitudes are used. However, the complete extinction by geologic standards of bony fishes could take 56–3500 years. None of the 16 approaches gave results below that observed at K–Pg, let alone levels representative of background extinction.

Hagfishes

Of the 76 species of hagfishes listed in the 2012 IUCN/SSC Red List, none are known to have gone extinct since 1500 or 1980 (Suppl. Table 2). Impaired (7.9 %) and data deficient (39.5 %) hagfishes raise the expected magnitude of extinction by geologic standards to 51.3 % since 1500. All of the impaired, and data deficient hagfishes would have disappeared from the fossil record since 1980.

There were no hagfish extinctions observed since 1500 (Table 2). Impaired and data deficient species provide an extinction magnitude at least 1194–11,757 times K–Pg.

If the extinction rate moving into the future (Table 1) is no larger than the magnitude of reptilian species that have already gone extinct during recent times, then complete extinction of all reptiles might occur in 30,200–222,600 years, depending on if the post-1980 or post-1500 extinction magnitudes are used. However, the complete extinction by geologic standards could take 59–2345 years.

Lampreys

Of the 38 species of lampreys listed in the 2012 IUCN/SSC Red List, only one extinction of a species has occurred since 1500, and it happened after 1980 (Suppl. Table 2). Impaired (7.9 %) and data deficient (10.5 %) lampreys raise the expected magnitude of extinction by geologic standards to 21.1 % since 1500. All (100 %) of the extinct, impaired, and data deficient lampreys would have disappeared from the fossil record since 1980.

The magnitude of lamprey extinction observed since 1500 is at least 42–1400 times the magnitude observed during the K–Pg mass extinction (Table 2). Inclusion of impaired and data deficient species increases to at least 500–7525 times K–Pg.

If the extinction rate moving into the future (Table 1) is no larger than the magnitude of lamprey species that have already gone extinct during recent times, then complete extinction of all lampreys might occur in 627–19,494 years, depending on if the post-1980 or post-1500 extinction magnitudes are used. However, the complete extinction by geologic standards of lampreys could take 48–2345 years. None of the 16 approaches gave results below that observed at K–Pg, let alone levels representative of background extinction.

Cartilaginous fishes

Of the 1093 species of cartilaginous fishes listed in the 2012 IUCN/SSC Red List, none are known to have gone extinct since 1500 (Suppl. Table 2). Impaired (16.7 %) and data deficient (45.9 %) cartilaginous fishes provide an expected extinction magnitude by geologic standards of 62.5 % since 1980. All (100 %) of the impaired and data deficient cartilaginous fishes would have disappeared from the fossil record since 1980. Impaired and data deficient species provide for an extinction magnitude of at least 1668–18,523 times K–Pg (Table 2). The complete extinction by geologic standards of cartilaginous fishes could take 53–821 years.

Discussion

Although impaired and data deficient species are used to simulate the resolution of the fossil record, I am not suggesting that these species are destined to go extinct. They simply are sufficiently rare that examination of a future fossil record would not recover them except, possibly as Lazarus taxa. This provides us with worst case scenarios for extinction for comparison to the best case scenario (no further extinction will occur). Further, there are of course problems with comparing the fossil record to the modern species record. This has been belabored in the literature, and the general consensus is that this is the best record we have, and certainly the most dependable record we have. There are also issues with generic versus species level assessments, which is why I have incorporated the generic and species level assessments into the fuzzy numbers for both the recent and ancient extinctions. This provided us with a range of possible extinction rates that span the possible scenarios while accounting for most uncertainty that exists.

The time frames provided for complete extinction are intended to emphasize the sheer magnitudes of recent extinctions, but many vertebrates might linger on long past these projections (Barnosky et al. 2011a, b; Wignall and Benton 1999). Even so, it is prudent to consider the current situation in these terms because they relate the dire nature of biodiversity preservation in a political climate where much of the public has become disinterested (McCallum and Bury 2013, 2014), funding biodiversity initiatives are not given priority (Lindenmayer et al. 2011; Bottrill et al. 2011), and the impacts of escalating climate change on organisms (Keith et al. 2014; McCallum et al. 2009; McCallum 2010). The cascade of events that would surely occur with such a large and rapid loss of biodiversity may very well stimulate further extinctions and ultimately the collapse of many ecosystems and food webs, and we are rapidly approaching the deadline for action.

The primary take-home from these results should be what is possible, remotely possible, and in all likelihood impossible in regard to current extinction magnitude, its comparison to previous geologic events, and the time required for contemporary vertebrate groups to become extinct (Suppl. Fig. 1; Abrahamsson 2002; Ferson et al. 1995; Zadeh 1990). The values reported in the text of the results do not include marginally possible levels that often exceed several levels of magnitude higher or lower than shown. For example, the text shows that the post-1500 extinction magnitude for vertebrates when data deficient and impaired species are included as extinct is 956–4016 times the magnitude of loss during the Cretaceous mass extinction. However, this range encompasses the fuzzy estimates provided by two different calculations, those with island endemics excluded and those with island endemics included. In this example, the two fuzzy sets overlap with very similar segments where $Y = 1$. This is not always the case. The area of marginal possibility in each fuzzy set (where $X = (0 < Y > 1)$ is provided in the Tables (Tables 1, 2). However, these marginal extinction levels and time frames become more possible as they approach $Y = 1$ and less possible as they approach $Y = 0$. So, in the case of post-1500 vertebrate extinction example X where $Y = 1$ is 956–4016, but extinction magnitudes between 4016–8474 times K–Pg are marginally possible ($0 < Y < 1$). So, as the extinction magnitude exceeds 4016 it becomes less possible until it becomes impossible for all X-values > 8474 times K–Pg. Likewise, as X-values become less possible as they diverge below 956 times K–Pg with any value less than 298 times K–Pg being impossible. Reptiles were the only group whose current biodiversity losses included estimates that were at or below the levels observed during the Cretaceous mass extinction (Tables 1, 2) despite 16 different approaches encompassing 288 separate computations.

These calculations demonstrate that current extinction estimates are surprisingly similar or more severe than the previous five mass extinctions (Table 1; Suppl. Fig. 2). Like the five previous mass extinctions, the projected losses fit the kill curve as a 1:100 MY event (Raup 1991). The current event put 21.1 % of contemporary vertebrates extinct by fossil record standards over the past 505 years; whereas, 36–45 % of non-dinosaur vertebrates went extinct over the entire 0.5–2.75 MY (Briggs 1991; Bowring et al. 1999; Benton 2005) encompassed by the Cretaceous mass extinction (Suppl. Table 1; Suppl. Fig. 2). The Great Permian Extinction saw the loss of 96 % of marine (Benton 2005) and 70 % of terrestrial vertebrates (Sahney and Benton 2008) during a span of 0.5 MY (Erwin 1990) to ~9 MY (Yin et al. 2007), although one recent study suggests it took only 50,000–100,000 years (Smith and Ward 2001; Erwin 1990; Bowring et al. 1999; Huey and Ward 2005; Payne and Clapham 2012). The Triassic-Jurassic mass extinction lasted less than 0.5 MY (Erwin 1990; Jablonski 1994). Herein, the estimates for time to total extinction, whether based on the post-1500 or post-1980 data, meet or exceed the magnitudes and loss rates of all these previous mass extinctions (Table 1; Suppl. Figs. 3–15).

Systematists have grown the number of species known on Earth very rapidly, especially with the application of molecular methods that help identify large numbers of sister taxa that once were identified as single species (Costello et al. 2013). Most of these new cryptic species are not endangered. Further, sister species often cannot be identified from fossils because of lacking molecular or morphological evidence. This should inflate the denominator in our calculations for percent modern extinctions compared to those in the fossil record, and mathematically deflate the impact of extinct and impaired species on percent extinction and impairment in modern times. Further, extinction in the fossil record almost certainly predates the actual disappearance of a species from the planet as populations dwindle, and ranges contract and fragment (Barnosky et al. 2011a; Wignall and Benton 1999). This suggests many species with conservation status, and those that remain unevaluated due to rareness, are already extinct by paleontological standards due to the resolution of the fossil record and Signor–Lipps effect (Signor and Lipps 1982). By comparison, estimates for modern extinctions are far more conservative because they are indicated when repeated surveys for species fail to find them (Barnosky et al. 2011a, b) and focus on only those groups for which attention has been paid (Diamond 1989). Despite this significant bias that should lower the magnitude of modern extinction relative to the fossil record, modern extinction is extraordinary high.

Impaired species (Wignall and Benton 1999; Newell 1959) and data deficient species (Barnosky et al. 2011a) often have smaller populations or ranges, so the opportunity to form fossils is much lower (Benton et al. 2011; Signor and Lipps 1982). These species should appear extinct due to the resolution of the fossil record. From a paleontological perspective, they represent dead clades walking (Jablonski 2002) or at best Lazarus taxa (Wignall and Benton 1999). This rationale provided motivation to present the alternative perspective with impaired species treated as extinct. Addition of impaired species markedly reduces the time needed for complete extinction.

My findings support previous reports that suggest current extinction rates and magnitudes are in line with the five mass extinctions. They reveal dramatically increased levels of extinction relative to the projected point estimates of 200–1500 E/MY (extinctions/million species years) published 20 years earlier (Pimm et al. 1995). The differences between Pimm et al.'s (1995) projections and those of (Barnosky et al. 2011a) and herein must at least partially stem from the much larger number of species that were evaluated by the IUCN since 1995 and 2011. Pimm's (2014) update reveals a magnitude of 1000 times background extinction. Clearly, there are some vertebrates that could survive an extinction of this extent, just as some vertebrates and invertebrates survived former extinctions despite massive losses of their relatives (Barnosky et al. 2011a, b; Pimm et al. 2006). There are even debates if some dinosaurs survived into the Paleocene (Fassett et al. 2012; Brusatte et al. 2014). However, as with former extinctions, this fact would not protect against significant ecological disturbances (Hewzulla et al. 1999; Milner 1998; Benton 2005; Barnosky et al. 2011b) and probable risk to humans.

In 1997 the median contemporary extinction rate of 41 species/day was sufficient to drive 96 % of modern biota extinct within 16,000 years (Sepkoski 1997). Little progress in slowing extinction has been made since that time. In fact, the best case scenarios herein suggest acceleration of overall vertebrate extinction despite possible reductions in extinction of birds and mammals.

The new IUCN and paleontological information altered estimates for various vertebrate groups. It increased the best estimate for the post-1980 amphibian extinction (McCallum 2007) by 25–129 %. The 2007 analysis showed that amphibian extinction since 1980 (including impaired species as extinct) was 28,792–39,487 larger than K–Pg; whereas, this updated analysis suggests it is 26,746–28,010 higher. Earlier work with mammals (Regan et al. 2001) found post-1500 extinction (excluding island endemics) was 36–78 times K–Pg, compared to 61–67 times K–Pg for mammals herein. A 2006 study (Pimm et al. 2006) reported that if the 182 birds then listed as critically endangered went extinct in the following 30 years, extinction levels would grow an "order of magnitude increase over extinctions-to-date." The number of critically endangered birds has now grown to 213 (IUCN/SSC Red List 2014). Further, a 1989 study reported that avian extinction magnitude was already sufficient to drive all birds extinct in 4500–9000 years (Diamond 1989). Herein, I suggest birds would go extinct in 156–38,016 years depending on which of the 16 scenarios are used. The differences among these studies originate from differences in methodology (point vs. interval vs. fuzzy approaches) and the effects of updates to the informational databases since the previous studies were published. However, the differences between the outcomes of these studies are trivial, especially when considering the message all are sending: Large scale biodiversity losses are well underway, and the future is bleak if action is not taken soon.

Before this study, there were insufficient reptile evaluations in the Red List to perform risk assessments of this kind. With 38 % of reptiles now evaluated, the first comparisons are now possible. Recent findings suggest $\sim$19 % of all extant reptile species are probably threatened with extinction (Baum et al. 2013) compared to the worst case scenario of 16.8 % I present. The rate of extinction for reptiles could be much higher than it was for non-dinosaur reptiles at K–Pg.

Recently, Dulvy et al. (2014) relayed that only 37.4 % of cartilaginous fishes were safe from extinction (this included NT species as at-risk, which we did not use in our calculations). The added species (new total: N = 362) from categories VU to CR used by (Dulvy et al. 2014) raise the post-1500 magnitude of extinction to 884–4450 times the extinction rate at K–Pg for cartilaginous fishes. This new information significantly increased the risk and concern for this group.

As the IUCN completes its SSC evaluations, the proportion of extinct and impaired amphibian species continues to rise; whereas, this proportion remained more stable for mammals and birds. The large differences in financial investment in conservation efforts and our generally better understanding of the life histories for mammals and birds compared to other groups may largely explain why bird and mammal extinction grew much slower relative to many other vertebrates (see Pimm et al. 2006; McCallum and McCallum 2006; Bury 2006). In fact, we know conservation practices produced ~33 % fewer bird extinctions than predicted from 1976–2006 (Pimm et al. 2006). This strongly suggests that similar investment in other groups could have avoided recent extinctions, and increased future investment could drastically improve future prospects. Currently, all vertebrates, even birds, are rapidly disappearing and overall extinction risk is much worse now than ever before.

The patterns of our current modern extinctions differ from those in previous mass extinctions in several ways. First, widespread and common species are generally least likely to go extinct (Jablonski 1986; Raup 1992). However, many recently extinct and currently impaired species were previously both common and widespread (e.g. Passenger Pigeon, Carolina Parakeet). Almost 73 % of extinctions at K–Pg involved the rarest species, often the last members of previously diverse groups (Bryant 1989). Further, young taxa are more susceptible to extinction than older ones probably due to their lower diversity and more restricted ranges (Boyajian 1991). However, the current extinction event appears to have no set pattern in this respect. Ancient vertebrate species (e.g. many amphibians, turtles and bony fishes) are under similar duress compared to relatively recently evolved groups (e.g. birds). Unlike taxa involved in earlier extinctions, virtually all modern extant taxa have low familial origination and extinction probabilities (Gilinsky 1994), making the unparalleled diversity losses among modern taxa inconceivable relative to previous geological scenarios.

Modern extinctions are probably most different from earlier episodes in that the ultimate causes of those earlier losses were largely extensive geological events of a sporadic nature (Hallam 1998; Milner 1998). Instead, *humans* are directly and indirectly (IUCN/SSC Red List 2012) undoing eons of evolution in the most rapid, self-destructive manner ever witnessed before on Earth, and some speculate that we are nearing a "point of no return," (Benn 2010). Fortunately, this is also the first episode in which a species was capable of doing something about extinction before it spirals out of control. Recent biodiversity losses and their importance have not gone unrecognized. In 2006, 193 nations agreed to reduce biodiversity losses by 2010 (Global Biodiverity Outlook 2 2006). Despite this, the agreement was an epic failure with extinctions continuing without clear restraint (Global Biodiversity Outlook 3 2010). In fact, the differences between Pimm et al. (1995) and more recent reports by Barnosky et al. (2011a), Pimm et al. (2014) and herein appear to support the findings of several other studies that show there has been little progress in slowing extinction (Butchart et al. 2010). In fact, it is moving faster than ever (Hoffman et al. 2010). Further, any attempt to rank the current relative extinction risk of one group of vertebrates against another is pointless because all vertebrate groups are simply under equally catastrophic duress.

Conclusion

Recent Vertebrate extinction moved forward 24–18,500 times faster than during the Cretaceous mass extinction. The magnitude of extinction has exploded since 1980. These extreme values arise due to the great speed with which vertebrate biodiversity is being decimated compared to the devastation of previous extinction events. If recent levels of extinction were to continue, the magnitude is sufficient to drive these groups extinct in less than a century.

The outcomes of this study combined with previously published research provide for a clear conclusion. Multiple, unrelated investigators have approached the question of a sixth mass extinction using multiple tools. Their message has been consistent. Further, mass mortality events have become more frequent for all extant taxa suggesting high risk of declines (Fey et al. 2015). Early reports warned that if nothing was done soon, we could be facing catastrophic losses (Wilson 1988; Ehrlich and Ehrlich 1981; Leakey and Lewin 1995). Despite these warnings, desperately needed public interest in environmental issues (Clements 2013) is indifferent at best (McCallum and Bury 2014, 2013; Richards 2013). Whether 1000 times background or 9000 times the extinction rate at K–Pg, it is blatantly obvious that biodiversity losses must be reined in.

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<u>Supplementary Materials</u>

Supplemental Discussion.

Supplemental Table 1. Paleontological biodiversity and extinction data used in calculations.

Supplemental Table 2. Recent species extinction and impairments.

Supplemental Figure 1. Explanation of fuzzy arithmetic.

Supplemental Figure 2. Estimates of the percent of contemporary species that are extinct and in danger of extinction, and estimates of percent extinction for the Cretaceous-Paleogene ($K - Pg$), Pleistocene, Permian, and Triassic-Jurassic extinctions.

Supplemental Figures 3 – 15. Graphed fuzzy numbers from calculations.

Supplemental Discussion

Point/probabilistic methods like these are very appealing because they have a long tradition, but they most appropriate where uncertainties are comparatively small and datasets are comparatively large (Belohlavek and Klir 2011; Li 2009; Abrahamsson 2002). Risk studies such as those investigating contemporary and ancient extinctions tend to have relatively large uncertainty and small probabilities (Alroy 2014) making point-based and probabilistic approaches less preferable. The large uncertainties in paleontological extinction studies and modern extinction assessments require incorporation of higher order approximations/assumptions that may very well be wrong (Alroy 2014; e.g. Barnosky et al. 2011), and the output is limited to the input parameters (e.g. mean, variance) (for a general discussion see Abrahamsson 2002, Darba et al. 2008). This implies potential for serious problems when assessing estimates of contemporary or ancient extinctions, because this risk is characterized by low probability – high consequence scenarios. In these kinds of studies, it is more important to eliminate those extinction levels that are impossible than to identify the exact extinction magnitude, especially where extreme catastrophe is apparent.

Interval analysis is very useful when the investigator has information restricted to the data range (Abrahamsson 2002 ; Darba et al. 2008; Ferson et al. 1995; 1996), especially for screening (Abrahamsson 2002). It is strait forward and easily explained and can be used with any source of uncertainty (Abrahamsson 2002). It is superior to point/probablistic estimates (used by Pimm et al. 1995, Pimm et al. 2005; Pimm et al. 2006) for extinction risk studies because interval analysis provides a range of values that are possible and eliminates those that are not possible. However, because it only considers/reports a data range, the ranges of extinction estimates can grow very quickly during calculations, without providing an understanding of the distribution function, hampering their usefulness for comparing modern extinction dynamics to paleontological findings (Abrahamsson 2002). Interval analysis does not allow incorporation of other information beyond the data range, leading to skewed or erroneous results, and can compound stochastic and knowledge-based uncertainty (Abrahamsson 2002, Darba et al. 2008). These issues are critical considerations when expressing the high-consequence risk of extinction and evaluating the findings of Barnosky et al. (2011), because there is no way to evaluate the relative importance of the various values within the interval estimate. Sometimes the fossil record is limited to a range of data, but usually it tells us much more. Modern extinctions almost always provide information beyond a simple range estimate. In these kind of scenarios, fuzzy approaches are much more useful. Fuzzy approaches do everything interval analysis does, but it has added utility because it provides the relative importance of the possible outcomes (Suppl. Fig. 1). Both past and modern extinction events tend to provide sufficient information for use of fuzzy tools.

Some contend that island endemics confound the results of the kinds of comparisons made in this paper because island endemics would be excluded from the fossil record (Regan et al. 2001); however, I believe this creates a different set of biases because terrestrial fossils from the Mesozoic do appear on at least some islands (Matsukawa et al. 1997; Flynn et al. 1999; Azuma and Currie 2000). Thus, I included calculations with and without island endemics to ensure any biases of either approach are not ignored. I do not distinguish between island and continental forms of marine species because the logic for addressing island endemics applies primarily to terrestrial and freshwater aquatic organisms (Regan et al. 2001).

Supplemental Table 1. Paleontological biodiversity and extinction data used in calculations[1].

	Amphibians	Birds	Mammals	Reptiles	Bony Fishes	Hagfishes	Lampreys	Cartilaginous Fishes	Non-dinosaur Vertebrates
Extinction rate at *K-Pg* boundary	33% 0%	0% 41%	33%	11% 0% 64% 73% 27% 20% 50% 83%	40% 10% 38%	?^	?^	60% 20%, 43.4% 84% $17\%_{fam}$ $56\%_{gen}$ $84\%_{spec}$	43% 39-45% 36%
Relative completeness index (RCI) and or Simple completeness metric (SCM)	0.39 0.423 0.75	0.639 0.776 0.976	0.65 0.67 0.70 0.976	0.684 0.704 0.75 0.802	0.55 0.69 0.84	0.55 0.69 0.84	0.55 0.69 0.84	0.55 0.69 0.85 0.94 0.94	0.39 0.704 0.976

^I used the non-dinosaur vertebrate extinction estimates for calculations with Hagfishes and Lampreys.
Data from: IUCN/SSC 2012; Clemmens 1986; Archibald and Bryant 1990; Fitch and Ayala 1995; Cooper and Penny 1997; Hou et al. 1996; Longrich et al. 2011; MacLeod et al. 1997; Benton 1998; Robertson et al. 2004; Longrich et al. 2012; Patterson 1993; Capetta 1987; Chiappe 1995; Clarke et al. 2005; Kriwet and Benton 2004; Bryant 1989; Fara and Benton 2000; Foote 1997; Fountaine et al. 2005; Benton 1998; Pimm 2002; Raup 1992; Benton 1998.

Supplemental Table 2. Recent species extinctions and impairments (IUCN/SSC Red List 2012).

	Amphibians	Birds	Mammals	Reptiles	Bony Fishes	Hagfishes	Lampreys	Cartilaginous fishes	Vertebrates
Post-1500									
Extinctions	38	134	79	22	66	0	1	0	340
Island Extinctions	0	120	36	18	2	0	0	0	176
Post-1980									
Extinctions	12	14	3	4	31	0	1	0	65
Island Extinctions	0	8	0	3	0	0	0	0	11
Other									
Extant Evaluated Species	6370	9930	5501	3663	9171	76	19	1093	35957
Extant island Species	1098	4173	1518	789	2108	37	6	722	10451
Impaired Species	1931	1179	1140	802	1937	9	3	182	7227
Impaired Island Species	338	549	405	281	241	7	1	123	2045
Data Deficient*	1614	62	799	811	2184	30	4	502	6006
Species Described	6671	10064	5501	9547	31193	76	38	1093	64283
% evaluated	97	100	100	38	29.4	100	50	100	56

*numbers for data deficient species are from the 2014 Red List because this was added in at the request of reviewers.

Supplemental Table 3. Equations used to evaluate biodiversity and extinction data.

Minimum percentage of extant species for each taxon that became extinct in recent times
$= (\mathrm{N}_{\text{recent extinctions for taxon}}/\mathrm{N}_{\text{extant species for taxon}}) \times 100$

Number of extinctions expected based on marine invertebrate background extinction rate.
$= (N_{\text{species in taxon}}/N_{\text{all species}}) \times$ marine invertebrate background extinction rate $\times \mathrm{T}_{\text{obs}}$

Per taxon rate of extinction (per million species years)
$= (N_{\text{taxon extinctions}}/N_{\text{species in taxon}}) \times (10^6/\mathrm{T}_{\text{obs}})$

Comparison of current extinctions for each taxon to *K-Pg* extinction rates for that taxon
$= ([\mathrm{N}_{\text{taxon extinctions}} \times \mathrm{CI}]/[\mathrm{N}_{\text{extant species in taxon}} \times (\mathrm{CI} \pm 10\%)]) \times (10^6/\mathrm{T}_{\text{obs}}) \times (1/R_{K\text{-}Pg})$;
where CI = either the fossil relative completedness index or fossil simple completedness Metric, T_{obs} = the time frame in question, and $R_{K\text{-}Pg}$ = the extinction rate of the taxon in question at the *K-Pg* boundary.

Comparison of current extinctions for each taxon to *K-Pg* extinction rates for that taxon with island endemics excluded:
$= ([(\mathrm{N}_{\text{taxon extinctions}} - \mathrm{N}_{\text{island taxon extinctions}}) \times \mathrm{CI}] /$
$[(\mathrm{N}_{\text{extant species in taxon}} - \mathrm{N}_{\text{extant island endemics in taxon}}) \times (\mathrm{CI} \pm 10\%)]) \times (10^6/\mathrm{T}_{\text{obs}}) \times (1/R_{K\text{-}Pg})$

Comparison of current extinctions for each taxon to *K-Pg* extinction rates for that taxon with island endemics included, and impaired species included as extinct:
$= ([(\mathrm{N}_{\text{taxon extinctions}} + \mathrm{N}_{\text{taxon impairments}}) \times \mathrm{CI}] /$
$[\mathrm{N}_{\text{extant species in taxon}} \times (\mathrm{CI} \pm 10\%)]) \times (10^6/\mathrm{T}_{\text{obs}}) \times (1/R_{K\text{-}Pg})$

Comparison of current extinctions for each taxon to K-Pg extinction rates for that taxon with island endemics included, and impaired species and data deficient species included as extinct:
$= ([(\mathrm{N}_{\text{taxon extinctions}} + \mathrm{N}_{\text{taxon impairments}} + \mathrm{N}_{\text{data deficient taxa}}) \times \mathrm{CI}] /$
$[\mathrm{N}_{\text{extant species in taxon}} \times (\mathrm{CI} \pm 10\%)]) \times (10^6/\mathrm{Tobs}) \times (1/\mathrm{R}_{\text{K-Pg}})$

Comparison of current extinctions for each taxon to K-Pg extinction rates for that taxon with island endemics excluded and impaired species included as extinct:
$= ([(\mathrm{N}_{\text{taxon extinctions}} + \mathrm{N}_{\text{taxon impairments}} - \mathrm{N}_{\text{taxon island endemic extinctions and impairments}}) \times \mathrm{CI}] /$
$[(\mathrm{N}_{\text{extant species in taxon}} - \mathrm{N}_{\text{extant island endemics}}) \times (\mathrm{CI} \pm 10\%)]) \times (10^6/\mathrm{T}_{\text{obs}}) \times (1/R_{K\text{-}Pg})$

Number of extinctions expected in recent times based on marine invertebrate extinction rate.
$= (N_{\text{species in taxon}}/N_{\text{all species}}) \times$ marine invertebrate background extinction rate $\times \mathrm{T}_{\text{obs}}$

Minimum rate of extinction per million years for each taxon
$= (\mathrm{N}_{\text{recent taxon extinctions}}/\mathrm{T}_{\text{obs}}) \times 10^6$

Years until total extinction or each taxon based on current extinction rate
$= (\mathrm{N}_{\text{extant taxon species}} \times \mathrm{T}_{\text{obs}}) / \mathrm{N}_{\text{recent taxon extinctions}})$

Years until total extinction or each taxon based on current extinction rate and excluding island endemics

$= ((N_{\text{extant taxon species}} - N_{\text{extant taxon island endemics}}) \times T_{\text{obs}}) /$
$(N_{\text{recent taxon extinctions}} - N_{\text{recent taxon extinctions of island endemics}})$

Years until total extinction for each taxon based on current extinction rate and including impaired species

$= ([N_{\text{extant taxon species}}] \times T_{\text{obs}}) / [N_{\text{recent taxon extinctions}} + N_{\text{taxon impairments}}])$

Years until total extinction for each taxon based on current extinction rate and including impaired species and data deficient species

$= ([N_{\text{extant taxon species}}] \times T_{\text{obs}}) / [N_{\text{recent taxon extinctions}} + N_{\text{taxon impairments}} + N_{\text{data deficient species}}])$

Years until total extinction or each taxon based on current extinction rate and excluding island endemics

$= ((N_{\text{extant taxa}} - N_{\text{extant island endemic taxa}}) \times T_{\text{obs}}) /$
$(N_{\text{recent taxon extinctions}} - N_{\text{recent extinctions of island endemic taxa}} + N_{\text{impaired taxa}})$

Supplemental Table 4. Calculations made using equations from Supplemental Table 3. All numbers in brackets ([]) are fuzzy numbers.

<u>Minimum percentage of extant species for each taxon that became extinct since 1500.</u>

$(N_{\text{recent extinctions for taxon}}/N_{\text{extant species for taxon}}) \times 100$

Amphibians
Extinctions = [N – 10%, N, N + 10%]
Extant species = [described – 10%, evaluated, described, described + 10%]
$(N_{\text{recent amphibian extinctions}}/N_{\text{extant amphibians}}) \times 100$
([34,38,42]/[5733,6370,6671,7338]) × 100 = [0.46,0.57,0.60,0.73]%

Birds
Extinctions = [N – 10%, N, N + 10%]
Extant species = [evaluated – 10%, evaluated, described, described + 10%]
$(N_{\text{recent avian extinctions}}/N_{\text{extant birds}}) \times 100$
([121,134,147]/[8937,9930,10064,11070]) × 100 = [1.10,1.33,1.35,1.64]%

Mammals
Extinctions = [N – 10%, N, N + 10%]
Extant species = [evaluated – 10%, evaluated, evaluated + 10%]
$(N_{\text{recent mammalian extinctions}}/N_{\text{extant mammals}}) \times 100$
([71,79,87]/[4951,5501,6051]) × 100 = [1.17,1.44,1.76]%

Reptiles
Extinctions = [N – 10%, N, N + 10%]
Extant species = [evaluated – 10%, evaluated, described, described + 10%]
$(N_{\text{recent reptilian extinctions}}/N_{\text{extant reptiles}}) \times 100$
([20,22,24]/[3297,3663,9547,10502]) × 100 = [0.19,0.23,0.60,0.73]%

Bony Fishes
Extinctions = [N – 10%, N, N + 10%]
Extant species = [evaluated – 10%, evaluated, described, described + 10%]
$(N_{\text{recent bony fish extinctions}}/N_{\text{extant bony fishes}}) \times 100$
([59,66,73]/[8254,9171,31193,34312]) × 100 = [0.17,0.21,0.72,0.88]%

Hagfishes (no extinctions so no calculations)

Lampreys
Extinctions = [N – 10%, N, N + 10%]
Extant species = [evaluated – 10%, evaluated, described, described + 10%]
$(N_{\text{recent lamprey extinctions}}/N_{\text{extant lampreys}}) \times 100$
([0.9,1,1.1]/[17,19,38,42]) × 100 = [2.14,2.63,5.26,6.47]%

Cartilaginous Fishes (no extinctions, no calculations)

Vertebrates
Extinctions = [N – 10%, N, N + 10%]
Extant species = [evaluated – 10%, evaluated, described, described + 10%]
$(N_{\text{recent vertebrate extinctions}}/N_{\text{extant vertebrates}}) \times 100$
$([306,340,374]/[32361,35957,64283,70711]) \times 100 = [0.43,0.53,0.95,1.16]\%$

<u>Minimum percentage of extant species for each taxon that became extinct since 1980.</u>

$(N_{\text{recent extinctions for taxon}}/N_{\text{extant species for taxon}}) \times 100$

Amphibians
Extinctions = [N – 10%, N, N + 10%]
Extant species = [described – 10%, evaluated, described, described + 10%]
$(N_{\text{recent amphibian extinctions}}/N_{\text{extant amphibians}}) \times 100$
$([11,12,13]/[5733,6370,6671,7338]) \times 100 = [0.15,0.18,0.19,0.23]\%$

Birds
Extinctions = [N – 10%, N, N + 10%]
Extant species = [evaluated – 10%, evaluated, described, described + 10%]
$(N_{\text{recent avian extinctions}}/N_{\text{extant birds}}) \times 100$
$([13,14,15]/[8937,9930,10064,11070]) \times 100 = [0.12,0.14,0.17]\%$

Mammals
Extinctions = [N – 10%, N, N + 10%]
Extant species = [evaluated – 10%, evaluated, evaluated + 10%]
$(N_{\text{recent mammalian extinctions}}/N_{\text{extant mammals}}) \times 100$
$([2.7,3,3.3]/[4951,5501,6051]) \times 100 = [0.04,0.05,0.07]\%$

Reptiles
Extinctions = [N – 10%, N, N + 10%]
Extant species = [evaluated – 10%, evaluated, described, described + 10%]
$(N_{\text{recent reptilian extinctions}}/N_{\text{extant reptiles}}) \times 100$
$([3,4,5]/[3297,3663,9547,10502]) \times 100 = [0.03,0.04,0.11,0.15]\%$

Bony Fishes
Extinctions = [N – 10%, N, N + 10%]
Extant species = [evaluated – 10%, evaluated, described, described + 10%]
$(N_{\text{recent bony fish extinctions}}/N_{\text{extant bony fishes}}) \times 100$
$([28,31,34]/[8254,9171,31193,34312]) \times 100 = [0.08,0.10,0.34,0.41]\%$

Hagfishes (no extinctions so no calculations)

Lampreys
Extinctions = [N – 10%, N, N + 10%]

Extant species = [evaluated – 10%, evaluated, described, described + 10%]
$(N_{\text{recent lamprey extinctions}}/N_{\text{extant lampreys}}) \times 100$
([0.9,1,1.1]/[17,19,38,42]) × 100 = [2.14,2.63,5.26,6.47]%

Cartilaginous Fishes (no extinctions, no calculations)

Vertebrates
Extinctions = [N – 10%, N, N + 10%]
Extant species = [evaluated – 10%, evaluated, described, described + 10%]
$(N_{\text{recent vertebrate extinctions}}/N_{\text{extant vertebrates}}) \times 100$
([59,65,72]/[32361,35957,64283,70711]) × 100 = [0.08,0.10,0.18,0.22]%

<u>Number of extinctions expected since 1500 AD based on the marine invertebrate background extinction rate.</u>

$(N_{\text{species in taxon}}/N_{\text{all species}})$ × marine invertebrate background extinction rate × 513 years

Amphibians
$(N_{\text{species of Amphibia}}/N_{\text{all species}})$ × marine invertebrate background extinction rate × 513 years
([5733,6370,6671,7338]/[1260000,1400000,10000000]) × (0.25/1000000) × 513 years =
[7e-8,6e-7,7e-7] amphibians

Birds
$(N_{\text{species of Aves}}/N_{\text{all species}})$ × marine invertebrate background extinction rate × 513 years
([8937,9930,10064,11070]/[1260000,1400000,10000000]) × (0.25/1000000) × 513 years =
[1e-7,9e-7,1e-6] birds

Mammals
$(N_{\text{species of mammals}}/N_{\text{all species}})$ × marine invertebrate background extinction rate × 513 years
([4951,5501,6051]/[1260000,1400000,10000000]) × (0.25/1000000) × 513 years =
[6e-8,5e-7,6e-7] mammals

Reptiles
$(N_{\text{species of reptiles}}/N_{\text{all species}})$ × marine invertebrate background extinction rate × 513 years
([3297,3663,9547,10502]/[1260000,1400000,10000000]) × (0.25/1000000) × 513 years =
[4e-8,3e-7,1e-6] reptiles

Bony Fishes
$(N_{\text{species of bony fishes}}/N_{\text{all species}})$ × marine invertebrate background extinction rate × 513 years
([8254,9171,31193,34312]/[1260000,1400000,10000000]) × (0.25/1000000) × 513 years =
[1e-7,8e-7,3e-6,3e-6] bony fishes

Hagfishes
$(N_{\text{species of hagfishes}}/N_{\text{all species}})$ × marine invertebrate background extinction rate × 513 years
([68,76,84]/[1260000,1400000,10000000]) × (0.25/1000000) × 513 years =
[9e-10,7e-9,8e-9] hagfishes

Lampreys
$(N_{\text{species of lampreys}}/N_{\text{all species}})$ × marine invertebrate background extinction rate × 513 years
([17,19,38,42]/[1260000,1400000,10000000]) × (0.25/1000000) × 513 years =
[2e-10,2e-9,3e-9,4e-9] lampreys

Cartilaginous Fishes
$(N_{\text{species of cartilaginous fishes}}/N_{\text{all species}})$ × marine invertebrate background extinction rate × 513 years
([984,1093,1202]/[1260000,1400000,10000000]) × (0.25/1000000) × 513 years =
[1.3e-8,1.0e-7,1.2e-7] cartilaginous fishes

Vertebrates
$(N_{\text{species of vertebrates}}/N_{\text{all species}})$ × marine invertebrate background extinction rate × 513 years
([32361,35957,64283,70711]/[1260000,1400000,10000000]) × (0.25/1000000) × 513 years =
[4.2e-7,3.3e-6,5.9e-6,7.2e-6] vertebrates

<u>Per taxon rate of extinction (per million species years) since 1500 AD.</u>

$(N_{\text{taxon extinctions}}/N_{\text{species in taxon}}) \times (10^6/513 \text{ years})$ = per taxon rate (the N expected to go extinct in 1 MY given the available number of species in that taxon with potential to go extinct).

Amphibians
$(N_{\text{Amphibian extinctions}}/N_{\text{species in Amphibia}}) \times (10^6/513 \text{ years})$ =
([34,38,42]/[5733,6370,6671,7338]) × $(10^6/513$ years) = [9,11,12,14] extinctions in 1 MY

Birds
$(N_{\text{Avian extinctions}}/N_{\text{species in Aves}}) \times (10^6/513 \text{ years})$ =
([121,134,147]/[8937,9930,10064,11070]) × $(10^6/513$ years) = [21,26,32] extinctions in 1 MY

Mammals
$(N_{\text{mammal extinctions}}/N_{\text{species in Mammalia}}) \times (10^6/513 \text{ years})$ =
([71,79,87]/[4951,5501,6051]) × $(10^6/513$ years) = [23,28,34] extinctions in 1 MY

Reptiles
$(N_{\text{Reptile extinctions}}/N_{\text{species in Reptilia}}) \times (10^6/513 \text{ years})$ =
([20,22,24]/[3297,3663,9547,10502]) × $(10^6/513$ years) = [4,5,14] extinctions in 1 MY

Bony Fishes
$(N_{\text{bony fish extinctions}}/N_{\text{species of bony fishes}}) \times (10^6/513 \text{ years})$ =
([59,66,73]/[8254,9171,31193,34312]) × $(10^6/513$ years) = [3,4,14,17] extinctions in 1 MY

Hagfishes
$(N_{\text{hagfish extinctions}}/N_{\text{species of hagfishes}}) \times (10^6/513 \text{ years})$ =
([0]/[68,76,84]) × $(10^6/513$ years) = [0] extinctions in 1 MY

Lampreys

$(N_{\text{hagfish extinctions}}/N_{\text{species of hagfishes}}) \times (10^6/513 \text{ years}) =$
$([0.9,1,1.1]/[17,19,38,42]) \times (10^6/513 \text{ years}) = [42,51,103,126]$ extinctions in 1 MY

Cartilaginous Fishes
$(N_{\text{cartilaginous fish extinctions}}/N_{\text{species of cartilaginous fishes}}) \times (10^6/513 \text{ years}) =$
$([0]/[984,1093,1202]) \times (10^6/513 \text{ years}) = [0]$ extinctions in 1 MY

Vertebrates
$(N_{\text{cartilaginous fish extinctions}}/N_{\text{species of cartilaginous fishes}}) \times (10^6/513 \text{ years}) =$
$([306,340,374]/[32361,35957,64283,70711]) \times (10^6/513 \text{ years}) = [0,10,18,23]$ extinctions in 1 MY

<u>Comparison of post-1500 extinctions to *K-Pg* extinction rate for each taxon with island endemics included.</u>

$([N_{\text{taxon extinctions}} \times \text{CI}]/[N_{\text{extant species in taxon}} \times (\text{CI} \pm 10\%)]) \times (10^6/\text{T}_{\text{obs}}) \times (1/R_{K\text{-}Pg})$

Amphibians
There are three available estimates for completedness (Suppl. 1)
$R_{K\text{-}Pg} = [0.1, \text{high estimate}, \text{high estimate} \times 1.1]$
(0.1 was substituted for zero for $R_{K\text{-}Pg}$ to avoid dividing by zero)
$([N_{\text{amphibian extinctions}} \times \text{CI}]/[N_{\text{extant species in Amphibia}} \times (\text{CI - 10\%, CI, CI}_{\text{high}})]) \times (10^6/\text{T}_{\text{obs}}) \times (1/R_{K\text{-}Pg})$
$(([34,38,42] \times [0.39,0.423,0.75])/([5733,6370,6671,7338] \times [0.38,0.423,0.75])) \times (10^6/513 \text{ yr}) \times (1/[0.1,0.33,0.36]) = [13,34,35,256]$

Birds
There are three available estimates for completedness (Suppl. 1)
$R_{K\text{-}Pg} = [0.1, \text{high estimate}, \text{high estimate} \times 1.1]$
(0.1 was substituted for zero for $R_{K\text{-}Pg}$ to avoid dividing by zero)
$([N_{\text{avian extinctions}} \times \text{CI}]/[N_{\text{extant species in Aves}} \times (\text{CI - 10\%, CI, CI}_{\text{high}})]) \times (10^6/\text{T}_{\text{obs}}) \times (1/R_{K\text{-}Pg})$
$(([121,134,147] \times [0.639,0.776,0.976])/([8937,9930,10064,11070] \times [0.575,0.639,0.776,0.976])) \times (10^6/513 \text{ yr}) \times (1/[0.1,0.41,0.45) = [31,63,78,544]$

Mammals
There are four available estimates for completedness (Suppl. 1)
$R_{K\text{-}Pg} = 0.33 \pm 10\%$
$([N_{\text{mammal extinctions}} \times \text{CI}]/[N_{\text{extant species in Mammalia}} \times (\text{CI - 10\%, CI, CI}_{\text{high}})]) \times (10^6/\text{T}_{\text{obs}}) \times (1/R_{K\text{-}Pg})$
$(([71,79,87] \times [0.65,0.67,0.70,0.976])/([4951,5501,6051] \times [0.60,0.67,0.70,0.976])) \times (10^6/513 \text{ yr}) \times (1/[0.30.33,0.36) = [42,81,89,186]$

Reptiles
There are three available estimates for completedness (Suppl. 1)
$R_{K\text{-}Pg} = [0.1, \text{high estimate}, \text{high estimate} \times 1.1]$ (there are eight estimates)
(0.1 was substituted for zero for $R_{K\text{-}Pg}$ to avoid dividing by zero)
$([N_{\text{reptile extinctions}} \times \text{CI}]/[N_{\text{extant reptiles}} \times (\text{CI - 10\%, CI, CI}_{\text{high}})]) \times (10^6/\text{T}_{\text{obs}}) \times (1/R_{K\text{-}Pg})$

$(([20,22,24] \times [0.684,0.704,0.750,0.802])/([3297,3663,9547,10502] \times [0.575,0.704,0.750,0.825])) \times (10^6/513 \text{ yr}) \times (1/[0.1,0.11,0.73,0.83]) = [4,6,113,198]$

Bony Fishes
There are three available estimates for completedness (Suppl. 1)
$R_{K\text{-}Pg}$ = [0.1, high estimate, high estimate × 1.1] (there are eight estimates)
(0.1 was substituted for zero for $R_{K\text{-}Pg}$ to avoid dividing by zero)
$([N_{\text{Bony fish extinctions}} \times \text{CI}]/[N_{\text{extant Bony fishes}} \times (\text{CI - 10\%, CI, CI}_{\text{high}})]) \times (10^6/\text{T}_{\text{obs}}) \times (1/R_{K\text{-}Pg})$
$(([59,66,73] \times [0.55,0.69,0.84])/([8254,9171,31193,34312] \times [0.50,0.55,0.84,0.92])) \times (10^6/513 \text{ yr}) \times (1/[0.1,0.38,0.40]) = [5,9,46,290]$

Hagfishes (no extinctions so no calculations)

Lampreys
There are three available estimates for completedness (Suppl. 1)
$R_{K\text{-}Pg}$ is unknown. The $R_{K\text{-}Pg}$ for cartilaginous fish was used as a surrogate.
$([N_{\text{lamprey extinctions}} \times \text{CI}]/[N_{\text{extant lampreys}} \times (\text{CI - 10\%, CI, CI}_{\text{high}})]) \times (10^6/\text{T}_{\text{obs}}) \times (1/R_{K\text{-}Pg})$
$(([0.9,1,1.1] \times [0.55,0.69,0.84])/([17,19,38,42] \times [0.50,0.55,0.84,0.92])) \times (10^6/513 \text{ yr}) \times (1/[0.17,0.20,0.60,0.84]) = [30,70,643,1246]$

Cartilaginous Fishes (no extinctions, no calculations)

Vertebrates
There are three available estimates for completedness (Suppl. 1)
$R_{K\text{-}Pg}$ = [low, med-low, med-high, high] (there are four estimates)
$([N_{\text{vertebrate extinctions}} \times \text{CI}]/[N_{\text{extant vertebrates}} \times (\text{CI - 10\%, CI, CI}_{\text{high}})]) \times (10^6/\text{T}_{\text{obs}}) \times (1/R_{K\text{-}Pg})$
$(([306,340,374] \times [0.39,0.704,0.976])/([32361,35957,64283,70711] \times [0.351,0.39,0.704,0.976])) \times (10^6/513 \text{ yr}) \times (1/[0.36,0.39,0.43,0.45]) = [7,24,85,174]$

<u>Comparison of post-1500 extinctions to *K-Pg* extinction rate for each taxon with both island endemics and data deficient species included.</u>

$(([N_{\text{taxon extinctions}} \times \text{CI}]+[N_{\text{data deficient}}])/[N_{\text{extant species in taxon}} \times (\text{CI} \pm 10\%)]) \times (10^6/\text{T}_{\text{obs}}) \times (1/R_{K\text{-}Pg})$

Amphibians
((([34,38,42]+[1614])*([0.39,0.423,0.75]))/([5733,6370,6671,7338]*[0.39,0.423,0.75]))*(1000000/513)*1/[0.1,0.33,0.36]) = [632.166,1462.366,1532.396,10831.51]

Birds
$((([121,134,147] + [62]) \times [0.639,0.776,0.976])/([8937,9930,10064,11070] \times [0.575,0.639,0.776,0.976])) \times (10^6/513 \text{ yr}) \times (1/[0.1,0.41,0.45) = [46.76,92.36,114.25,776.63]$

Mammals
$((([71,79,87] + [799]) \times [0.65,0.67,0.70,0.976])/([4951,5501,6051] \times [0.60,0.67,0.70,0.976])) \times (10^6/513 \text{ yr}) \times (1/[0.30,0.33,0.36) = [237.94,454.52,496.70,3910.52]$

Reptiles

$(([20,22,24] \times [0.684,0.704,0.750,0.802])/([3297,3663,9547,10502] \times [0.575,0.704,0.750,0.825])) \times (10^6/513\text{ yr}) \times (1/[0.1,0.11,0.73,0.83]) = [153.98,218.57,4295.83,6889.96]$

Bony Fishes

$((([59,66,73] + [2184]) \times [0.55,0.69,0.84])/([8254,9171,31193,34312] \times [0.50,0.55,0.84,0.92])) \times (10^6/513\text{ yr}) \times (1/[0.1,0.38,0.40]) = [190.41, 303.87, 1579.24, 8956.85]$

Hagfishes (no extinctions so no calculations)

Lampreys

$((([0.9,1,1.1]+[4]) \times [0.55,0.69,0.84])/([17,19,38,42] \times [0.50,0.55,0.84,0.92])) \times (10^6/513\text{ yr}) \times (1/[0.17,0.20,0.60,0.84]) = [145.34, 316.03, 3539.55, 6345.74]$

Cartilaginous Fishes (no extinctions, no calculations)

Vertebrates

$((([306,340,374] +[6006]) \times [0.39,0.704,0.976])/([32361,35957,64283,70711] \times [0.351,0.39,0.704,0.976])) \times (10^6/513\text{ yr}) \times (1/[0.36,0.39,0.43,0.45]) = [154.50, 447.49, 1592.49, 2968.63]$

<u>Comparison of post-1500 extinctions to *K-Pg* extinction rate for each taxon with island endemics excluded.</u>

$([(N_{\text{taxon extinctions}} - N_{\text{taxon island extinctions}}) \times \text{CI}]/[N_{\text{extant species in taxon}} - N_{\text{extant island species in taxon}}) \times (\text{CI} \pm 10\%)]) \times (10^6/\text{T}_{\text{obs}}) \times (1/R_{K\text{-}Pg})$

Amphibians

There are three available estimates for completedness (Suppl. 1)

$R_{K\text{-}Pg}$ = [0.1, high estimate, high estimate × 1.1]

(0.1 was substituted for zero for $R_{K\text{-}Pg}$ to avoid dividing by zero)

$([(N_{\text{amphibian extinctions}} - N_{\text{amphibian island extinctions}} \times \text{CI}]/[N_{\text{extant species in Amphibia}} - N_{\text{extant island species in Amphibia}}) \times (\text{CI - }10\%, \text{CI}, \text{CI}_{\text{high}})]) \times (10^6/\text{T}_{\text{obs}}) \times (1/R_{K\text{-}Pg})$

$(([34,38,42] \times [0.39,0.423,0.75])/(([5733,6370,6671,7338] - [988,1098,1208]) \times [0.38,0.423,0.75])) \times (10^6/513\text{ yr}) \times (1/[0.1,0.33,0.36]) = [15,40,43,357]$

Birds

There are three available estimates for completedness (Suppl. 1)

$R_{K\text{-}Pg}$ = [0.1, high estimate, high estimate × 1.1]

(0.1 was substituted for zero for $R_{K\text{-}Pg}$ to avoid dividing by zero)

$([N_{\text{avian extinctions}} \times \text{CI}]/[N_{\text{extant species in Aves}} \times (\text{CI - }10\%, \text{CI}, \text{CI}_{\text{high}})]) \times (10^6/\text{T}_{\text{obs}}) \times (1/R_{K\text{-}Pg})$

$((([121,134,147] - [108,120,132]) \times [0.639,0.776,0.976])/(([8937,9930,10064,11070] - [3756,4173,4590]) \times [0.575,0.639,0.776,0.976])) \times (10^6/513\text{ yr}) \times (1/[0.1,0.41,0.45]) = [-84,11,14,297]$

Mammals
There are four available estimates for completedness (Suppl. 1)
$R_{K\text{-}Pg}$ = 0.33 ± 10%
$([N_{\text{mammal extinctions}} \times \text{CI}]/[N_{\text{extant species in Mammalia}} \times (\text{CI - 10\%, CI, CI}_{\text{high}})]) \times (10^6/\text{T}_{\text{obs}}) \times (1/R_{K\text{-}Pg})$
((([71,79,87] – [32,36,40]) × [0.65,0.67,0.70,0.976])/(([4951,5501,6051] – [1366,1518,1670]) × [0.60,0.67,0.70,0.976])) × (10^6/513 yr) × (1/[0.30.33,0.36]) = [24,61,67,177]

Reptiles
There are three available estimates for completedness (Suppl. 1)
$R_{K\text{-}Pg}$ = [0.1, high estimate, high estimate × 1.1] (there are eight estimates)
(0.1 was substituted for zero for $R_{K\text{-}Pg}$ to avoid dividing by zero)
$([N_{\text{reptile extinctions}} \times \text{CI}]/[N_{\text{extant reptiles}} \times (\text{CI - 10\%, CI, CI}_{\text{high}})]) \times (10^6/\text{T}_{\text{obs}}) \times (1/R_{K\text{-}Pg})$
((([20,22,24] – [16,18,20])× [0.684,0.704,0.750,0.802])/(([3297,3663,9547,10502] – [710,789,868]) × [0.575,0.704,0.750,0.825])) × (10^6/513 yr) × (1/[0.1,0.11,0.73,0.83]) = [0,1,26,90]

Bony Fishes
There are three available estimates for completedness (Suppl. 1)
$R_{K\text{-}Pg}$ = [0.1, high estimate, high estimate × 1.1] (there are eight estimates)
(0.1 was substituted for zero for $R_{K\text{-}Pg}$ to avoid dividing by zero)
$([N_{\text{Bony fish extinctions}} \times \text{CI}]/[N_{\text{extant bony fishes}} \times (\text{CI - 10\%, CI, CI}_{\text{high}})]) \times (10^6/\text{T}_{\text{obs}}) \times (1/R_{K\text{-}Pg})$
((([59,66,73] – [1.8,2,2.2]) × [0.55,0.69,0.84])/(([8254,9171,31193,34312] – [1897,2108,2319]) × [0.50,0.55,0.84,0.92])) × (10^6/513 yr) × (1/[0.1,0.38,0.40]) = [5,9,58,392]

Hagfishes (no extinctions so no calculations)

Lampreys
There are three available estimates for completedness (Suppl. 1)
$R_{K\text{-}Pg}$ is unknown. The $R_{K\text{-}Pg}$ for cartilaginous fish was used as a surrogate.
$([N_{\text{lamprey extinctions}} \times \text{CI}]/[N_{\text{extant lampreys}} \times (\text{CI - 10\%, CI, CI}_{\text{high}})]) \times (10^6/\text{T}_{\text{obs}}) \times (1/R_{K\text{-}Pg})$
(([0.9,1,1.1] × [0.55,0.69,0.84])/(([17,19,38,42] – [5,6,7]) × [0.50,0.55,0.84,0.92])) × (10^6/513 yr) × (1/[0.17,0.20,0.60,0.84]) = [15,42,1411,3082]

Cartilaginous Fishes (no extinctions, no calculations)

Vertebrates
There are three available estimates for completedness (Suppl. 1)
$R_{K\text{-}Pg}$ = [low, med-low, med-high, high] (there are four estimates)
$([N_{\text{vertebrate extinctions}} \times \text{CI}]/[N_{\text{extant vertebrates}} \times (\text{CI - 10\%, CI, CI}_{\text{high}})]) \times (10^6/\text{T}_{\text{obs}}) \times (1/R_{K\text{-}Pg})$
((([306,340,374] – [158,176,194]) × [0.39,0.704,0.976])/(([32361,35957,64283,70711] – [9406,10451,11496]) × [0.351,0.39,0.704,0.976])) × (10^6/513 yr) × (1/[0.36,0.39,0.43,0.45]) = [3,14,58,156]

Comparison of post-1500 extinctions to *K-Pg* extinction rate for each taxon with island endemics excluded and data deficient species included.

Amphibians
(([34,38,42]+[1614]-[0]) × [0.39,0.423,0.75])/(([5733,6370,6671,7338] – [988,1098,1208]) × [0.38,0.423,0.75])) × (10^6/513 yr) × (1/[0.1,0.33,0.36]) = [730.30,1749.95,1852.12,13727.24]

Birds
((([121,134,147] + [62] – [108,120,132]) × [0.639,0.776,0.976])/(([8937,9930,10064,11070] − [3756,4173,4590]) × [0.575,0.639,0.776,0.976])) × (10^6/513 yr) × (1/[0.1,0.41,0.45]) = [55.26,128.73,160.97,1703.81]

Mammals
((([71,79,87] + [799] – [32,36,40]) × [0.65,0.67,0.70,0.976])/(([4951,5501,6051] – [1366,1518,1670]) × [0.60,0.67,0.70,0.976])) × (10^6/513 yr) × (1/[0.30.33,0.36]) = [293.17,602.00,657.89,5687.93]

Reptiles
((([20,22,24] +[811] – [16,18,20])× [0.684,0.704,0.750,0.802])/(([3297,3663,9547,10502] – [710,789,868]) × [0.575,0.704,0.750,0.825])) × (10^6/513 yr) × (1/[0.1,0.11,0.73,0.83]) = [161.17,233.11,5356.93,9172.98]

Bony Fishes
((([59,66,73] + [2184] – [1.8,2,2.2]) × [0.55,0.69,0.84])/(([8254,9171,31193,34312] – [1897,2108,2319]) × [0.50,0.55,0.84,0.92])) × (10^6/513 yr) × (1/[0.1,0.38,0.40]) = [201.28,325.61,2048.75,12450.65]

Hagfishes
((([30] * [[0.55,0.69,0.84])/([68,76,84] * [0.5,0.55,0.84,0.92])) * (10^6/513) * (1/[0.17,0.20,0.60,0.84]) = [670.40,1676.50,11130.2,25050.06]

Lampreys
((([0.9,1,1.1] + [4]) × [0.55,0.69,0.84])/(([17,19,38,42] – [5,6,7]) × [0.50,0.55,0.84,0.92])) × (10^6/513 yr) × (1/[0.17,0.20,0.60,0.84]) = [146,334,5643,11751]

Cartilaginous Fishes
((([502]) * [0.55,0.69,0.84])/([984,1093,1202] * [0.50,0.55,0.84,0.92])) * (10^6/513 yr) * (1/[0.17,0.20,0.60,0.84]) = [578.24,1223.26,5627.13,9847.27]

Vertebrates
There are three available estimates for completedness (Suppl. 1)
$R_{K\text{-}Pg}$ = [low, med-low, med-high, high] (there are four estimates)
([$N_{\text{vertebrate extinctions}}$ × CI]/[$N_{\text{extant vertebrates}}$ × (CI - 10%, CI, CI_{high})]) × ($10^6/\text{T}_{\text{obs}}$) × ($1/R_{K\text{-}Pg}$)

$(((\text{[306,340,374]} – \text{[158,176,194]}) \times \text{[0.39,0.704,0.976]})/((\text{[32361,35957,64283,70711]} – \text{[9406,10451,11496]}) \times \text{[0.351,0.39,0.704,0.976]})) \times (10^6/513\text{ yr}) \times (1/\text{[0.36,0.39,0.43,0.45]}) = \text{[175.73,519.54,2182.79,4275.90]}$

<u>Comparison of post-1500 extinctions to *K-Pg* extinction rate for each taxon with island endemics and impaired species included.</u>

$([(N_{\text{taxon extinctions}} + N_{\text{taxon impaired species}}) \times \text{CI}]/[N_{\text{extant species in taxon}}] \times (\text{CI} \pm 10\%)]) \times (10^6/\text{T}_{\text{obs}}) \times (1/R_{K\text{-}Pg})$

Amphibians
There are three available estimates for completedness (Suppl. 1)
$R_{K\text{-}Pg}$ = [0.1, high estimate, high estimate × 1.1]
(0.1 was substituted for zero for $R_{K\text{-}Pg}$ to avoid dividing by zero)
$([(N_{\text{amphibian extinctions}} + N_{\text{impaired amphibians)}} \times \text{CI}]/[N_{\text{extant species in Amphibia}}) \times (\text{CI - 10\%, CI, CI}_{\text{high}})]) \times (10^6/\text{T}_{\text{obs}}) \times (1/R_{K\text{-}Pg})$
$(((\text{[34,38,42]} + \text{[1738,1931,2124]}) \times \text{[0.39,0.423,0.75]})/(\text{[5733,6370,6671,7338]} \times \text{[0.38,0.423,0.75]})) \times (10^6/513\text{ yr}) \times (1/\text{[0.1,0.33,0.36]}) = \text{[679,1744,1826,14536]}$

Birds
There are three available estimates for completedness (Suppl. 1)
$R_{K\text{-}Pg}$ = [0.1, high estimate, high estimate × 1.1]
(0.1 was substituted for zero for $R_{K\text{-}Pg}$ to avoid dividing by zero)
$([(N_{\text{avian extinctions}} + N_{\text{impaired birds}}) \times \text{CI}]/[N_{\text{extant species in Aves}} \times (\text{CI - 10\%, CI, CI}_{\text{high}})]) \times (10^6/\text{T}_{\text{obs}}) \times (1/R_{K\text{-}Pg})$
$(((\text{[121,134,147]} + \text{[1067,1179,1297]}) \times \text{[0.639,0.776,0.976]})/(\text{[8937,9930,10064,11070]} \times \text{[0.575,0.639,0.776,0.976]})) \times (10^6/513\text{ yr}) \times (1/\text{[0.1,0.41,0.45]}) = \text{[304,620,763,5346]}$

Mammals
There are four available estimates for completedness (Suppl. 1)
$R_{K\text{-}Pg} = 0.33 \pm 10\%$
$([(N_{\text{mammal extinctions}} + N_{\text{impaired mammals}}) \times \text{CI}]/[N_{\text{extant species in Mammalia}} \times (\text{CI - 10\%, CI, CI}_{\text{high}})]) \times (10^6/\text{T}_{\text{obs}}) \times (1/R_{K\text{-}Pg})$
$(((\text{[71,79,87]} + \text{[1026,1140,1254]}) \times \text{[0.65,0.67,0.70,0.976]})/(\text{[4951,5501,6051]} \times \text{[0.60,0.67,0.70,0.976]})) \times (10^6/513\text{ yr}) \times (1/\text{[0.30,.33,0.36]}) = \text{[654,1253,1368,2863]}$

Reptiles
There are three available estimates for completedness (Suppl. 1)
$R_{K\text{-}Pg}$ = [0.1, high estimate, high estimate × 1.1] (there are eight estimates)
(0.1 was substituted for zero for $R_{K\text{-}Pg}$ to avoid dividing by zero)
$([(N_{\text{reptile extinctions}} + \text{N}_{\text{impaired reptiles}}) \times \text{CI}]/[N_{\text{extant reptiles}} \times (\text{CI - 10\%, CI, CI}_{\text{high}})]) \times (10^6/\text{T}_{\text{obs}}) \times (1/R_{K\text{-}Pg})$
$(((\text{[20,22,24]} + \text{[722,802,882]}) \times \text{[0.684,0.704,0.750,0.802]})/(\text{[3297,3663,9547,10502]} \times \text{[0.575,0.704,0.750,0.825]})) \times (10^6/513\text{ yr}) \times (1/\text{[0.1,0.11,0.73,0.83]}) = \text{[285,416,1229,7471]}$

Bony Fishes
There are three available estimates for completedness (Suppl. 1)
$R_{K\text{-}Pg}$ = [0.1, high estimate, high estimate × 1.1] (there are eight estimates)
(0.1 was substituted for zero for $R_{K\text{-}Pg}$ to avoid dividing by zero)
$([N_{\text{bony fish extinctions}} + N_{\text{impaired bony fishes}}) \times \text{CI}]/[N_{\text{extant bony fishes}} \times (\text{CI - 10\%, CI, CI}_{\text{high}})]) \times (10^6/\text{T}_{\text{obs}}) \times (1/R_{K\text{-}Pg})$
$((([59,66,73] + [1743,1937,2131]) \times [0.55,0.69,0.84])/([8254,9171,31193,34312] \times [0.50,0.55,0.84,0.92])) \times (10^6/513 \text{ yr}) \times (1/[0.1,0.38,0.40]) = [153,271,1406,8745]$

Hagfishes
There are three available estimates for completedness (Suppl. 1)
$R_{K\text{-}Pg}$ is unknown. The $R_{K\text{-}Pg}$ for cartilaginous fish was used as a surrogate.
$([N_{\text{hagfish extinctions}} + N_{\text{impaired hagfishes}}) \times \text{CI}]/[N_{\text{extant hagfishes}} \times (\text{CI - 10\%, CI, CI}_{\text{high}})]) \times (10^6/\text{T}_{\text{obs}}) \times (1/R_{K\text{-}Pg})$
$(([8,9,10] \times [0.55,0.69,0.84])/([68,76,84] \times [0.50,0.55,0.84,0.92])) \times (10^6/513 \text{ yr}) \times (1/[0.17,0.20,0.60,0.84]) = [124,298,1528,2975]$

Lampreys
There are three available estimates for completedness (Suppl. 1)
$R_{K\text{-}Pg}$ is unknown. The $R_{K\text{-}Pg}$ for cartilaginous fish was used as a surrogate.
$([N_{\text{reptile extinctions}} + \text{N}_{\text{impaired lampreys}}) \times \text{CI}]/[N_{\text{extant lampreys}} \times (\text{CI - 10\%, CI, CI}_{\text{high}})]) \times (10^6/\text{T}_{\text{obs}}) \times (1/R_{K\text{-}Pg})$
$((([0.9,1,1.1] + [2,3,4]) \times [0.55,0.69,0.84])/(([17,19,38,42]) \times [0.50,0.55,0.84,0.92])) \times (10^6/513 \text{ yr}) \times (1/[0.17,0.20,0.60,0.84]) = [96,281,2574,5779]$

Cartilaginous Fishes
There are three available estimates for completedness (Suppl. 1)
$R_{K\text{-}Pg}$ is unknown. The $R_{K\text{-}Pg}$ for cartilaginous fish was used as a surrogate.
$([N_{\text{cartilaginous fish extinctions}} + N_{\text{impaired cartilaginous fishes}}) \times \text{CI}]/[N_{\text{extant cartilaginous fishes}} \times (\text{CI - 10\%, CI, CI}_{\text{high}})]) \times (10^6/\text{T}_{\text{obs}}) \times (1/R_{K\text{-}Pg})$
$(([164,182,200] \times [0.55,0.69,0.84])/([984,1093,1202] \times [0.50,0.55,0.84,0.92])) \times (10^6/513 \text{ yr}) \times (1/[0.17,0.20,0.60,0.84]) = [189,443,2042,3925]$

Vertebrates
There are three available estimates for completedness (Suppl. 1)
$R_{K\text{-}Pg}$ = [low, med-low, med-high, high] (there are four estimates)
$([N_{\text{vertebrate extinctions}} + \text{N}_{\text{impaired vertebrates}}) \times \text{CI}]/[N_{\text{extant vertebrates}} \times (\text{CI - 10\%, CI, CI}_{\text{high}})]) \times (10^6/\text{T}_{\text{obs}}) \times (1/R_{K\text{-}Pg})$
$((([306,340,374] + [6504,7227,7950]) \times [0.39,0.704,0.976])/([32361,35957,64283,70711] \times [0.351,0.39,0.704,0.976])) \times (10^6/513 \text{ yr}) \times (1/[0.36,0.39,0.43,0.45]) = [167,534,1899,3873]$

Comparison of post-1500 extinctions to K-Pg extinction rate for each taxon with island endemic, data deficient, and impaired species included.

$((([N_{\text{taxon extinctions}}] \times \text{CI}) + [N_{\text{data deficient}}] + ([N_{\text{impaired species}}] \times \text{CI})) / [N_{\text{extant species in taxon}}] \times (\text{CI} \pm 10\%)) \times (10^6/\text{T}_{\text{obs}}) \times (1/R_{K\text{-}Pg})$

Amphibians
((([34,38,42]+[1614]+[1738,1931,2124])*([0.39,0.423,0.75]*[1738,1931,2124]))/([5733,6370,6671,7338]*[0.39,0.423,0.75]))*(1000000/513)*1/[0.1,0.33,0.36]) = [1299.058,3172.224,3323.049,24719.9]

Birds
$((([121,134,147] + [1067,1179,1297] + [62]) \times [0.639,0.776,0.976])/([8937,9930,10064,11070] \times [0.575,0.639,0.776,0.976])) \times (10^6/513 \text{ yr}) \times (1/[0.1,0.41,0.45]) =$ [320.12,649.34,799.78,5577.53]

Mammals
There are four available estimates for completedness (Suppl. 1)
$R_{K\text{-}Pg} = 0.33 \pm 10\%$
$([(N_{\text{mammal extinctions}} + N_{\text{impaired mammals}}) \times \text{CI}]/[N_{\text{extant species in Mammalia}} \times (\text{CI - 10\%, CI, CI}_{\text{high}})]) \times (10^6/\text{T}_{\text{obs}}) \times (1/R_{K\text{-}Pg})$
$((([71,79,87] + [1026,1140,1254] + [799]) \times [0.65,0.67,0.70,0.976])/([4951,5501,6051] \times [0.60,0.67,0.70,0.976])) \times (10^6/513 \text{ yr}) \times (1/[0.30,.33,0.36]) =$ [518.7,1045.013,1141.26,9442.15]

Reptiles
There are three available estimates for completedness (Suppl. 1)
$R_{K\text{-}Pg}$ = [0.1, high estimate, high estimate × 1.1] (there are eight estimates)
(0.1 was substituted for zero for $R_{K\text{-}Pg}$ to avoid dividing by zero)
$([(N_{\text{reptile extinctions}} + \text{N}_{\text{impaired reptiles}}) \times \text{CI}]/[N_{\text{extant reptiles}} \times (\text{CI - 10\%, CI, CI}_{\text{high}})]) \times (10^6/\text{T}_{\text{obs}}) \times (1/R_{K\text{-}Pg})$
$((([20,22,24] + [722,802,882]) \times [0.684,0.704,0.750,0.802])/([3297,3663,9547,10502] \times [0.575,0.704,0.750,0.825])) \times (10^6/513 \text{ yr}) \times (1/[0.1,0.11,0.73,0.83]) =$ [287.85,429.13,8429.31,14163.39]

Bony Fishes
There are three available estimates for completedness (Suppl. 1)
$R_{K\text{-}Pg}$ = [0.1, high estimate, high estimate × 1.1] (there are eight estimates)
(0.1 was substituted for zero for $R_{K\text{-}Pg}$ to avoid dividing by zero)
$([N_{\text{bony fish extinctions}} + N_{\text{impaired bony fishes}}) \times \text{CI}]/[N_{\text{extant bony fishes}} \times (\text{CI - 10\%, CI, CI}_{\text{high}})]) \times (10^6/\text{T}_{\text{obs}}) \times (1/R_{K\text{-}Pg})$
$((([59,66,73] + [1743,1937,2131] + [2184]) \times [0.55,0.69,0.84])/([8254,9171,31193,34312] \times [0.50,0.55,0.84,0.92])) \times (10^6/513 \text{ yr}) \times (1/[0.1,0.38,0.40]) =$ [338.40,565.54,2938.49,17411.8]

Hagfishes
There are three available estimates for completedness (Suppl. 1)
$R_{K\text{-}Pg}$ is unknown. The $R_{K\text{-}Pg}$ for cartilaginous fish was used as a surrogate.

$([N_{\text{hagfish extinctions}} + N_{\text{impaired hagfishes}}) \times \text{CI}]/[N_{\text{extant hagfishes}} \times (\text{CI - 10\%, CI, CI}_{\text{high}})]) \times (10^6/\text{T}_{\text{obs}}) \times (1/R_{K\text{-}Pg})$
$((([8,9,10] + [30]) \times [0.55,0.69,0.84])/([68,76,84] \times [0.50,0.55,0.84,0.92])) \times (10^6/513 \text{ yr}) \times (1/[0.17,0.20,0.60,0.84]) = [545.0205, 1193.896, 7079.102, 12748.14]$

Lampreys
There are three available estimates for completedness (Suppl. 1)
$R_{K\text{-}Pg}$ is unknown. The $R_{K\text{-}Pg}$ for cartilaginous fish was used as a surrogate.
$([N_{\text{reptile extinctions}} + \text{N}_{\text{impaired lampreys}}) \times \text{CI}]/[N_{\text{extant lampreys}} \times (\text{CI - 10\%, CI, CI}_{\text{high}})]) \times (10^6/\text{T}_{\text{obs}}) \times (1/R_{K\text{-}Pg})$
$((([0.9,1,1.1] + [2,3,4]) \times [0.55,0.69,0.84])/(([17,19,38,42]) \times [0.50,0.55,0.84,0.92])) \times (10^6/513 \text{ yr}) \times (1/[0.17,0.20,0.60,0.84]) = [211.40,526.72,5470.22,10878.41]$

Cartilaginous Fishes
There are three available estimates for completedness (Suppl. 1)
$R_{K\text{-}Pg}$ is unknown. The $R_{K\text{-}Pg}$ for cartilaginous fish was used as a surrogate.
$([N_{\text{cartilaginous fish extinctions}} + N_{\text{impaired cartilaginous fishes}}) \times \text{CI}]/[N_{\text{extant cartilaginous fishes}} \times (\text{CI - 10\%, CI, CI}_{\text{high}})]) \times (10^6/\text{T}_{\text{obs}}) \times (1/R_{K\text{-}Pg})$
$(([164,182,200] \times [0.55,0.69,0.84])/([984,1093,1202] \times [0.50,0.55,0.84,0.92])) \times (10^6/513 \text{ yr}) \times (1/[0.17,0.20,0.60,0.84]) = [768.11,1668.86,7657.59,13752.9]$

Vertebrates
There are three available estimates for completedness (Suppl. 1)
$R_{K\text{-}Pg}$ = [low, med-low, med-high, high] (there are four estimates)
$([N_{\text{vertebrate extinctions}} + \text{N}_{\text{impaired vertebrates}}) \times \text{CI}]/[N_{\text{extant vertebrates}} \times (\text{CI - 10\%, CI, CI}_{\text{high}})]) \times (10^6/\text{T}_{\text{obs}}) \times (1/R_{K\text{-}Pg})$
$((([306,340,374] + [6504,7227,7950]) \times [0.39,0.704,0.976])/([32361,35957,64283,70711] \times [0.351,0.39,0.704,0.976])) \times (10^6/513 \text{ yr}) \times (1/[0.36,0.39,0.43,0.45]) = [313.71,957.15,3405.92,6667.49]$

Comparison of post-1500 extinctions to *K-Pg* extinction rate for each taxon with island endemics excluded and impaired species included.

$([((N_{\text{taxon extinctions}} - N_{\text{taxon island extinctions}}) + (\text{N}_{\text{impaired species}} - \text{N}_{\text{impaired island species}})) \times \text{CI}]/[N_{\text{extant species in taxon}} - N_{\text{extant island species in taxon}}) \times (\text{CI} \pm 10\%)]]) \times (10^6/\text{T}_{\text{obs}}) \times (1/R_{K\text{-}Pg})$

Amphibians
There are three available estimates for completedness (Suppl. 1)
$R_{K\text{-}Pg}$ = [0.1, high estimate, high estimate × 1.1]
(0.1 was substituted for zero for $R_{K\text{-}Pg}$ to avoid dividing by zero)
$([((N_{\text{amphibian extinctions}} - N_{\text{island amphibian extinctions}}) + (N_{\text{impaired amphibians}} - N_{\text{island impaired amphibians}}) \times \text{CI}]/([N_{\text{extant species in Amphibia}}] - [N_{\text{extant island amphibians}}]) \times (\text{CI - 10\%, CI, CI}_{\text{high}})]) \times (10^6/\text{T}_{\text{obs}}) \times (1/R_{K\text{-}Pg})$
$(((([34,38,42] - [0]) + ([1738,1931,2124] - [304,338,372]) \times [0.39,0.423,0.75])/(([5733,6370,6671,7338] - [988,1098,1208]) \times [0.38,0.423,0.75])) \times (10^6/513 \text{ yr}) \times (1/[0.1,0.33,0.36]) = [621,1728,1828,15836]$

Birds

There are three available estimates for completedness (Suppl. 1)

$R_{K\text{-}Pg}$ = [0.1, high estimate, high estimate × 1.1]

(0.1 was substituted for zero for $R_{K\text{-}Pg}$ to avoid dividing by zero)

$([((N_{\text{avian extinctions}} - N_{\text{island avian extinctions}}) + (N_{\text{impaired avians}} - N_{\text{island impaired avians}}) \times \text{CI}]/([N_{\text{extant species in Avia}}] - [N_{\text{extant island avians}}]) \times (\text{CI - 10\%, CI, CI}_{\text{high}})]) \times (10^6/\text{T}_{\text{obs}}) \times (1/R_{K\text{-}Pg})$

(((([121,134,147] – [116,120,142]) + ([1067,1179,1297] – [494,549,604]) × [0.639,0.776,0.976])/(([8937,9930,10064,11070] – [3756,4173,5490]) × [0.575,0.639,0.776,0.976])) × (10^6/513 yr) × (1/[0.1,0.41,0.45]) = [167,523,650,8013]

Mammals

There are four available estimates for completedness (Suppl. 1)

$R_{K\text{-}Pg}$ = 0.33 ± 10%

$([((N_{\text{mammalian extinctions}} - N_{\text{island mammal extinctions}}) + (N_{\text{impaired mammals}} - N_{\text{island impaired mammals}}) \times \text{CI}]/([N_{\text{extant species in Mammalia}}] - [N_{\text{extant island mammals}}]) \times (\text{CI - 10\%, CI, CI}_{\text{high}})]) \times (10^6/\text{T}_{\text{obs}}) \times (1/R_{K\text{-}Pg})$

(((([71,79,87] – [32,36,40]) + ([1026,1140,1254]-[365,405,446])) × [0.65,0.67,0.70,0.976])/(([4951,5501,6051]-[1366,1518,1670]) × [0.60,0.67,0.70,0.976])) × (10^6/513 yr) × (1/[0.30,.33,0.36]) = [470,1104,1205,3041]

Reptiles

There are three available estimates for completedness (Suppl. 1)

$R_{K\text{-}Pg}$ = [0.1, high estimate, high estimate × 1.1] (there are eight estimates)

(0.1 was substituted for zero for $R_{K\text{-}Pg}$ to avoid dividing by zero)

$([((N_{\text{reptile extinctions}} - N_{\text{island reptile extinctions}}) + (N_{\text{impaired reptiles}} - N_{\text{island impaired reptiles}}) \times \text{CI}]/([N_{\text{extant species in Reptilia}}] - [N_{\text{extant island reptiles}}]) \times (\text{CI - 10\%, CI, CI}_{\text{high}})]) \times (10^6/\text{T}_{\text{obs}}) \times (1/R_{K\text{-}Pg})$

(((([20,22,24] – [16,18,20]) + ([722,802,882] – [253,281,309]))× [0.684,0.704,0.750,0.802])/(([3297,3663,9547,10502] – [710,789,868]) × [0.575,0.704,0.750,0.825])) × (10^6/513 yr) × (1/[0.1,0.11,0.73,0.83]) = [82,150,3449,7130]

Bony Fishes

There are three available estimates for completedness (Suppl. 1)

$R_{K\text{-}Pg}$ = [0.1, high estimate, high estimate × 1.1] (there are eight estimates)

(0.1 was substituted for zero for $R_{K\text{-}Pg}$ to avoid dividing by zero)

$([((N_{\text{bony fish extinctions}} - N_{\text{island bony fish extinctions}}) + (N_{\text{impaired impaired bony fishes}} - N_{\text{island impaired bony fishes}}) \times \text{CI}]/([N_{\text{extant bony fishes}}] - [N_{\text{extant island bony fishes}}]) \times (\text{CI - 10\%, CI, CI}_{\text{high}})]) \times (10^6/\text{T}_{\text{obs}}) \times (1/R_{K\text{-}Pg})$

(((([59,66,73] – [1.8,2,2.2]) + ([1743,1937,2131]-[217,241,265])) × [0.55,0.69,0.84])/(([8254,9171,31193,34312]-[1897,2108,2319])× [0.50,0.55,0.84,0.92])) × (10^6/513 yr) × (1/[0.1,0.38,0.40]) = [138,255,1604,10954]

Hagfishes
There are three available estimates for completedness (Suppl. 1)
$([((N_{\text{hagfish extinctions}} - N_{\text{island hagfish extinctions}}) + (N_{\text{impaired hagfishes}} - N_{\text{island impaired hagfishes}}) \times \text{CI}]/([N_{\text{extant hagfishes}}] - [N_{\text{extant island hagfishes}}]) \times (\text{CI - 10\%, CI, CI}_{\text{high}})]) \times (10^6/\text{T}_{\text{obs}}) \times (1/R_{K\text{-}Pg})$
$((([8,9,10]-[6,7,8]) \times [0.55,0.69,0.84])/(([68,76,84]-[33,37,41]) \times [0.50,0.55,0.84,0.92])) \times (10^6/513 \text{ yr}) \times (1/[0.17,0.20,0.60,0.84]) = [-713,68,940,3567]$

Lampreys
There are three available estimates for completedness (Suppl. 1)
$R_{K\text{-}Pg}$ is unknown. The $R_{K\text{-}Pg}$ for cartilaginous fish was used as a surrogate.
$([((N_{\text{lamprey extinctions}} - N_{\text{island lamprey extinctions}}) + (N_{\text{impaired lampreys}} - N_{\text{island impaired lampreys}}) \times \text{CI}]/([N_{\text{extant lampreys}}] - [N_{\text{extant island lampreys}}]) \times (\text{CI - 10\%, CI, CI}_{\text{high}})]) \times (10^6/\text{T}_{\text{obs}}) \times (1/R_{K\text{-}Pg})$
$(((([0.9,1,1.1]-[0]) + ([2,3,4]-[0.9,1,1.1])) \times ([0.55,0.69,0.84]))/(([17,19,38,42]-[5,6,7]) \times [0.50,0.55,0.84,0.92])) \times (10^6/513 \text{ yr}) \times (1/[0.17,0.20,0.60,0.84]) = [49,208,3292,9054]$

Cartilaginous Fishes
There are three available estimates for completedness (Suppl. 1)
$R_{K\text{-}Pg}$ is unknown. The $R_{K\text{-}Pg}$ for cartilaginous fish was used as a surrogate.
$([((N_{\text{cartilaginous fish extinctions}} - N_{\text{island cartilaginous fish extinctions}}) + (N_{\text{impaired cartilaginous fishes}} - N_{\text{island impaired cartilaginous fishes}}) \times \text{CI}]/([N_{\text{extant cartilaginous fishes}}] - [N_{\text{extant island cartilaginous fishes}}]) \times (\text{CI - 10\%, CI, CI}_{\text{high}})]) \times (10^6/\text{T}_{\text{obs}}) \times (1/R_{K\text{-}Pg})$
$((([164,182,200]-[111,123,135]) \times [0.55,0.69,0.84])/(([984,1093,1202]-[650,722,794]) \times [0.50,0.55,0.84,0.92])) \times (10^6/513 \text{ yr}) \times (1/[0.17,0.20,0.60,0.84]) = [70,417,1978,9125]$

Vertebrates
There are three available estimates for completedness (Suppl. 1)
$R_{K\text{-}Pg}$ = [low, med-low, med-high, high] (there are four estimates)
$([((N_{\text{vertebrate extinctions}} - N_{\text{island vertebrate extinctions}}) + (N_{\text{impaired vertebrates}} - N_{\text{island impaired vertebrates}}) \times \text{CI}]/([N_{\text{extant species in Vertebrata}}] - [N_{\text{extant island vertebrates}}]) \times (\text{CI - 10\%, CI, CI}_{\text{high}})]) \times (10^6/\text{T}_{\text{obs}}) \times (1/R_{K\text{-}Pg})$
$(((([306,340,374]-[158,176,194]) + ([6504,7227,7950]-[1841,2045,2250])) \times [0.39,0.704,0.976])/(([32361,35957,64283,70711]-[9406,10451,11496]) \times [0.351,0.39,0.704,0.976])) \times (10^6/513 \text{ yr}) \times (1/[0.36,0.39,0.43,0.45]) = [123,450,1891,4564]$

<u>Comparison of post-1500 extinctions to *K-Pg* extinction rate for each taxon with island endemics excluded and impaired and data deficient species included.</u>

Amphibians
$(((([34,38,42]\ [1614] - [0]\ ) + ([1738,1931,2124] - [304,338,372]) \times [0.39,0.423,0.75])/(([5733,6370,6671,7338] - [988,1098,1208]) \times [0.38,0.423,0.75])) \times (10^6/513 \text{ yr}) \times (1/[0.1,0.33,0.36]) = [1336,3438.43,3636.99,28804.84]$

Birds

$$((((([121,134,147] + [62] - [116,120,142]) + ([1067,1179,1297] - [494,549,604]) \times [0.639,0.776,0.976])/(([8937,9930,10064,11070] - [3756,4173,5490]) \times [0.575,0.639,0.776,0.976])) \times (10^6/513\ \text{yr}) \times (1/[0.1,0.41,0.45]) = [234.79,637.18,792.80,9411.76)]$$

Mammals

$$((((([71,79,87] + [799] - [32,36,40]) + ([1026,1140,1254]-[365,405,446])) \times [0.65,0.67,0.70,0.976])/(([4951,5501,6051]-[1366,1518,1670]) \times [0.60,0.67,0.70,0.976])) \times (10^6/513\ \text{yr}) \times (1/[0.30,.33,0.36]) = [212.59,602,657.89,7205.6]$$

Reptiles

$$((((([20,22,24] + [811] - [16,18,20]) + ([722,802,882] - [253,281,309]))\times [0.684,0.704,0.750,0.802])/(([3297,3663,9547,10502] - [710,789,868]) \times [0.575,0.704,0.750,0.825])) \times (10^6/513\ \text{yr}) \times (1/[0.1,0.11,0.73,0.83]) = [243.30,382.22,8779.32,16213.63]$$

Bony Fishes

$$((((([59,66,73] + [2184] - [1.8,2,2.2]) + ([1743,1937,2131]-[217,241,265])) \times [0.55,0.69,0.84])/(([8254,9171,31193,34312]-[1897,2108,2319])\times [0.50,0.55,0.84,0.92])) \times (10^6/513\ \text{yr}) \times (1/[0.1,0.38,0.40]) = [334.11,571.32,3594.08,23012.04]$$

Hagfishes

$$(((([8,9,10]+[30]-[6,7,8]) \times [0.55,0.69,0.84])/(([68,76,84]-[33,37,41]) \times [0.50,0.55,0.84,0.92])) \times (10^6/513\ \text{yr}) \times (1/[0.17,0.20,0.60,0.84]) = [670.40,1813.35,11757.25,27872.6]$$

Lampreys

$$((((([0.9,1,1.1]+[4]-[0]) + ([2,3,4]-[0.9,1,1.1])) \times ([0.55,0.69,0.84]))/(([17,19,38,42]-[5,6,7]) \times [0.50,0.55,0.84,0.92])) \times (10^6/513\ \text{yr}) \times (1/[0.17,0.20,0.60,0.84]) = [179.98,500.38,7524.64,17722.74]$$

Cartilaginous Fishes

$$(((([164,182,200]+[502]-[111,123,135]) \times [0.55,0.69,0.84])/(([984,1093,1202]-[650,722,794]) \times [0.50,0.55,0.84,0.92])) \times (10^6/513\ \text{yr}) \times (1/[0.17,0.20,0.60,0.84]) = [1330.80,4028.24,18522.58,60115.79]$$

Vertebrates

$$((((([306,340,374]+[6006]-[158,176,194]) + ([6504,7227,7950]-[1841,2045,2250])) \times [0.39,0.704,0.976])/(([32361,35957,64283,70711]-[9406,10451,11496]) \times [0.351,0.39,0.704,0.976])) \times (10^6/513\ \text{yr}) \times (1/[0.36,0.39,0.43,0.45]) = [297.94,955.92,4015.91,8474.42]$$

Number of extinctions expected since 1980 AD based on the marine invertebrate background extinction rate.

($N_{\text{species in taxon}}/N_{\text{all species}}$) × marine invertebrate background extinction rate × 33 years

Amphibians
($N_{\text{species of Amphibia}}/N_{\text{all species}}$) × marine invertebrate background extinction rate × 33 years
([5733,6370,6671,7338]/[1260000,1400000,10000000]) × (0.25/1000000) × 33 years =
[4.7e-9,3.8e-8,3.9e-8,4.8e-8] amphibians in 33 years

Birds
($N_{\text{species of Aves}}/N_{\text{all species}}$) × marine invertebrate background extinction rate × 33 years
([8937,9930,10064,11070]/[1260000,1400000,10000000]) × (0.25/1000000) × 33 years =
[7.4e-9,5.9e-8,5.9e-8,7.2e-8] birds in 33 years

Mammals
($N_{\text{species of mammals}}/N_{\text{all species}}$) × marine invertebrate background extinction rate × 33 years
([4951,5501,6051]/[1260000,1400000,10000000]) × (0.25/1000000) × 33 years =
[4.1e-9,3.2e-8,4.0e-8] mammals in 33 years

Reptiles
($N_{\text{species of reptiles}}/N_{\text{all species}}$) × marine invertebrate background extinction rate × 33 years
([3297,3663,9547,10502]/[1260000,1400000,10000000]) × (0.25/1000000) × 33 years =
[2.7e-9,2.2e-8,5.6e-8,6.9e-8] reptiles in 33 years

Bony Fishes
($N_{\text{species of bony fishes}}/N_{\text{all species}}$) × marine invertebrate background extinction rate × 33 years
([8254,9171,31193,34312]/[1260000,1400000,10000000]) × (0.25/1000000) × 33 years =
[6.8e-9,5.4e-8,1.8e-7,2.2e-7] bony fishes in 33 years

Hagfishes
($N_{\text{species of hagfishes}}/N_{\text{all species}}$) × marine invertebrate background extinction rate × 33 years
([68,76,84]/[1260000,1400000,10000000]) × (0.25/1000000) × 33 years =
[5.6e-11,4.5e-10,5.5e-10] hagfishes in 33 years

Lampreys
($N_{\text{species of lampreys}}/N_{\text{all species}}$) × marine invertebrate background extinction rate × 33 years
([17,19,38,42]/[1260000,1400000,10000000]) × (0.25/1000000) × 33 years =
[1.4e-11,1.1e-10,2.2e-10,2.8e-10] lampreys in 33 years

Cartilaginous Fishes
($N_{\text{species of cartilaginous fishes}}/N_{\text{all species}}$) × marine invertebrate background extinction rate × 33 years
([984,1093,1202]/[1260000,1400000,10000000]) × (0.25/1000000) × 33 years =
[8.1e-10,6.4e-9,7.9e-9] cartilaginous fishes in 33 years

Vertebrates
($N_{\text{species of vertebrates}}/N_{\text{all species}}$) × marine invertebrate background extinction rate × 33 years
([32361,35957,64283,70711]/[1260000,1400000,10000000]) × (0.25/1000000) × 33 years = [2.7e-8,2.1e-7,3.8e-7,4.6e-7] vertebrates in 33 years

Per taxon rate of extinction (per million species years) since 1980 AD.

($N_{\text{taxon extinctions}}/N_{\text{species in taxon}}$) × ($10^6$/33 years) = per taxon rate (the N expected to go extinct in 1 MY given the available number of species in that taxon with potential to go extinct).

Amphibians
($N_{\text{Amphibian extinctions}}/N_{\text{species in Amphibia}}$) × ($10^6$/33 years) =
([11,12,13]/[5733,6370,6671,7338]) × (10^6/33 years) = [45,55,57,69] extinctions in 1 MY

Birds
($N_{\text{Avian extinctions}}/N_{\text{species in Aves}}$) × ($10^6$/33 years) =
([14]/[8937,9930,10064,11070]) × (10^6/33 years) = [36,42,43,51] extinctions in 1 MY

Mammals
($N_{\text{mammal extinctions}}/N_{\text{species in Mammalia}}$) × ($10^6$/33 years) =
([2.7,3,3.3]/[4951,5501,6051]) × (10^6/33 years) = [14,17,20] extinctions in 1 MY

Reptiles
($N_{\text{Reptile extinctions}}/N_{\text{species in Reptilia}}$) × ($10^6$/33 years) =
([3.6,4,4.4]/[3297,3663,9547,10502]) × (10^6/33 years) = [10,13,33,40] extinctions in 1 MY

Bony Fishes
($N_{\text{bony fish extinctions}}/N_{\text{species of bony fishes}}$) × ($10^6$/33 years) =
([28,31,34]/[8254,9171,31193,34312]) × (10^6/33 years) = [25,30,102,125] extinctions in 1 MY

Hagfishes
($N_{\text{hagfish extinctions}}/N_{\text{species of hagfishes}}$) × ($10^6$/33 years) =
([0]/[68,76,84]) × (10^6/33 years) = [0] extinctions in 1 MY

Lampreys
($N_{\text{hagfish extinctions}}/N_{\text{species of hagfishes}}$) × ($10^6$/33 years) =
([0.9,1,1.1]/[17,19,38,42]) × (10^6/33 years) = [42,51,103,126] extinctions in 1 MY

Cartilaginous Fishes
($N_{\text{cartilaginous fish extinctions}}/N_{\text{species of cartilaginous fishes}}$) × ($10^6$/513 years) =
([0]/[984,1093,1202]) × (10^6/33 years) = [0] extinctions in 1 MY

Vertebrates
($N_{\text{cartilaginous fish extinctions}}/N_{\text{species of cartilaginous fishes}}$) × ($10^6$/33 years) =
([59,65,72]/[32361,35957,64283,70711]) × (10^6/33 years) = [26,31,55,67] extinctions in 1 MY

Comparison of post-1980 extinctions to *K-Pg* extinction rate for each taxon with island endemics included.

$([N_{\text{taxon extinctions}} \times \text{CI}]/[N_{\text{extant species in taxon}} \times (\text{CI} \pm 10\%)]) \times (10^6/\text{T}_{\text{obs}}) \times (1/R_{K\text{-}Pg})$

Amphibians
There are three available estimates for completedness (Suppl. 1)
$R_{K\text{-}Pg}$ = [0.1, high estimate, high estimate × 1.1]
(0.1 was substituted for zero for $R_{K\text{-}Pg}$ to avoid dividing by zero)
$([N_{\text{amphibian extinctions}} \times \text{CI}]/[N_{\text{extant species in Amphibia}} \times (\text{CI - 10\%, CI, CI}_{\text{high}})]) \times (10^6/\text{T}_{\text{obs}}) \times (1/R_{K\text{-}Pg})$
(([11,12,13] × [0.39,0.423,0.75])/([5733,6370,6671,7338] × [0.38,0.423,0.75])) × (10^6/33 yr) × (1/[0.1,0.33,0.36]) = [66,165,173,1356]

Birds
There are three available estimates for completedness (Suppl. 1)
$R_{K\text{-}Pg}$ = [0.1, high estimate, high estimate × 1.1]
(0.1 was substituted for zero for $R_{K\text{-}Pg}$ to avoid dividing by zero)
$([N_{\text{avian extinctions}} \times \text{CI}]/[N_{\text{extant species in Aves}} \times (\text{CI - 10\%, CI, CI}_{\text{high}})]) \times (10^6/\text{T}_{\text{obs}}) \times (1/R_{K\text{-}Pg})$
(([13,14,15] × [0.639,0.776,0.976])/([8937,9930,10064,11070] × [0.575,0.639,0.776,0.976])) × (10^6/33 yr) × (1/[0.1,0.41,0.45) = [52,103,127,863]

Mammals
There are four available estimates for completedness (Suppl. 1)
$R_{K\text{-}Pg}$ = 0.33 ± 10%
$([N_{\text{mammal extinctions}} \times \text{CI}]/[N_{\text{extant species in Mammalia}} \times (\text{CI - 10\%, CI, CI}_{\text{high}})]) \times (10^6/\text{T}_{\text{obs}}) \times (1/R_{K\text{-}Pg})$
(([2.7,3,3.3] × [0.65,0.67,0.70,0.976])/([4951,5501,6051] × [0.60,0.67,0.70,0.976])) × (10^6/33 yr) × (1/[0.30,.33,0.36) = [25,48,52,110]

Reptiles
There are three available estimates for completedness (Suppl. 1)
$R_{K\text{-}Pg}$ = [0.1, high estimate, high estimate × 1.1] (there are eight estimates)
(0.1 was substituted for zero for $R_{K\text{-}Pg}$ to avoid dividing by zero)
$([N_{\text{reptile extinctions}} \times \text{CI}]/[N_{\text{extant reptiles}} \times (\text{CI - 10\%, CI, CI}_{\text{high}})]) \times (10^6/\text{T}_{\text{obs}}) \times (1/R_{K\text{-}Pg})$
(([3.6,4,4.4] × [0.684,0.704,0.750,0.802])/([3297,3663,9547,10502] × [0.575,0.704,0.750,0.825])) × (10^6/33 yr) × (1/[0.1,0.11,0.73,0.83]) = [10,16,320,564]

Bony Fishes
There are three available estimates for completedness (Suppl. 1)
$R_{K\text{-}Pg}$ = [0.1, high estimate, high estimate × 1.1] (there are eight estimates)
(0.1 was substituted for zero for $R_{K\text{-}Pg}$ to avoid dividing by zero)
$([N_{\text{Bony fish extinctions}} \times \text{CI}]/[N_{\text{extant Bony fishes}} \times (\text{CI - 10\%, CI, CI}_{\text{high}})]) \times (10^6/\text{T}_{\text{obs}}) \times (1/R_{K\text{-}Pg})$
(([28,31,34] × [0.55,0.69,0.84])/([8254,9171,31193,34312] × [0.50,0.55,0.84,0.92])) × (10^6/33 yr) × (1/[0.1,0.38,0.40]) = [37,65,338,2097]

Hagfishes (no extinctions so no calculations)

Lampreys
There are three available estimates for completedness (Suppl. 1)
$R_{K\text{-}Pg}$ is unknown. The $R_{K\text{-}Pg}$ for cartilaginous fish was used as a surrogate.
$([N_{\text{lamprey extinctions}} \times \text{CI}]/[N_{\text{extant lampreys}} \times (\text{CI - 10\%, CI, CI}_{\text{high}})]) \times (10^6/\text{T}_{\text{obs}}) \times (1/R_{K\text{-}Pg})$
$(([0.9,1,1.1] \times [0.55,0.69,0.84])/([17,19,38,42] \times [0.50,0.55,0.84,0.92])) \times (10^6/33 \text{ yr}) \times (1/[0.17,0.20,0.60,0.84]) = [462,1092,10004,19377]$

Cartilaginous Fishes (no extinctions, no calculations)

Vertebrates
There are three available estimates for completedness (Suppl. 1)
$R_{K\text{-}Pg}$ = [low, med-low, med-high, high] (there are four estimates)
$([N_{\text{vertebrate extinctions}} \times \text{CI}]/[N_{\text{extant vertebrates}} \times (\text{CI - 10\%, CI, CI}_{\text{high}})]) \times (10^6/\text{T}_{\text{obs}}) \times (1/R_{K\text{-}Pg})$
$(([59,65,72] \times [0.39,0.704,0.976])/([32361,35957,64283,70711] \times [0.351,0.39,0.704,0.976])) \times (10^6/33 \text{ yr}) \times (1/[0.36,0.39,0.43,0.45]) = [22,71,253,521]$

Comparison of post-1980 extinctions to *K-Pg* extinction rate for each taxon with island endemics included and data deficient species included.

$([N_{\text{taxon extinctions}} \times \text{CI}]/[N_{\text{extant species in taxon}} \times (\text{CI} \pm 10\%)]) \times (10^6/\text{T}_{\text{obs}}) \times (1/R_{K\text{-}Pg})$

Amphibians
There are three available estimates for completedness (Suppl. 1)
$R_{K\text{-}Pg}$ = [0.1, high estimate, high estimate × 1.1]
(0.1 was substituted for zero for $R_{K\text{-}Pg}$ to avoid dividing by zero)
$([N_{\text{amphibian extinctions}} \times \text{CI}]/[N_{\text{extant species in Amphibia}} \times (\text{CI - 10\%, CI, CI}_{\text{high}})]) \times (10^6/\text{T}_{\text{obs}}) \times (1/R_{K\text{-}Pg})$
$(((([11,12,13] \times [0.39,0.423,0.75])+[1614])/([5733,6370,6671,7338] \times [0.38,0.423,0.75])) \times (10^6/33 \text{ yr}) \times (1/[0.1,0.33,0.36]) = [24743.81,52671.28,55194.23,220136.7]$

Birds
There are three available estimates for completedness (Suppl. 1)
$R_{K\text{-}Pg}$ = [0.1, high estimate, high estimate × 1.1]
(0.1 was substituted for zero for $R_{K\text{-}Pg}$ to avoid dividing by zero)
$([N_{\text{avian extinctions}} \times \text{CI}]/[N_{\text{extant species in Aves}} \times (\text{CI - 10\%, CI, CI}_{\text{high}})]) \times (10^6/\text{T}_{\text{obs}}) \times (1/R_{K\text{-}Pg})$
$((([13,14,15] \times [0.639,0.776,0.976])+[62])/([8937,9930,10064,11070] \times [0.575,0.639,0.776,0.976])) \times (10^6/33 \text{ yr}) \times (1/[0.1,0.41,0.45) = [435.09,684.85,854.55,4548.90]$

Mammals
There are four available estimates for completedness (Suppl. 1)
$R_{K\text{-}Pg} = 0.33 \pm 10\%$
$([N_{\text{mammal extinctions}} \times \text{CI}]/[N_{\text{extant species in Mammalia}} \times (\text{CI - 10\%, CI, CI}_{\text{high}})]) \times (10^6/\text{T}_{\text{obs}}) \times (1/R_{K\text{-}Pg})$
$(([2.7,3,3.3] \times [0.65,0.67,0.70,0.976])+[799])/([4951,5501,6051] \times [0.60,0.67,0.70,0.976])) \times (10^6/33 \text{ yr}) \times (1/[0.1,0.41,0.45]) = [9124.83,15364.88,16074.73,81885.39]$

Reptiles
There are three available estimates for completedness (Suppl. 1)
$R_{K\text{-}Pg}$ = [0.1, high estimate, high estimate × 1.1] (there are eight estimates)
(0.1 was substituted for zero for $R_{K\text{-}Pg}$ to avoid dividing by zero)
$([N_{\text{reptile extinctions}} \times \text{CI}]/[N_{\text{extant reptiles}} \times (\text{CI - 10\%, CI, CI}_{\text{high}})]) \times (10^6/\text{T}_{\text{obs}}) \times (1/R_{K\text{-}Pg})$
(([3.6,4,4.4] × [0.684,0.704,0.750,0.802])/([3297,3663,9547,10502] × [0.575,0.704,0.750,0.825])) × (10^6/33 yr) × (1/[0.1,0.11,0.73,0.83]) = [3425.72,4715.14,87011.15,130278.4]

Bony Fishes
There are three available estimates for completedness (Suppl. 1)
$R_{K\text{-}Pg}$ = [0.1, high estimate, high estimate × 1.1] (there are eight estimates)
(0.1 was substituted for zero for $R_{K\text{-}Pg}$ to avoid dividing by zero)
$([N_{\text{Bony fish extinctions}} \times \text{CI}]/[N_{\text{extant Bony fishes}} \times (\text{CI - 10\%, CI, CI}_{\text{high}})]) \times (10^6/\text{T}_{\text{obs}}) \times (1/R_{K\text{-}Pg})$
(([28,31,34] × [0.55,0.69,0.84])+[811])/([8254,9171,31193,34312] × [0.50,0.55,0.84,0.92])) × (10^6/33 yr) × (1/[0.1,0.38,0.40]) = [1982.07,2531.81,13167.73,61682.5]

Hagfishes (no extinctions so no calculations)
((([30]-[0]) * [0.55,0.69,0.84])/((([68,76,84]-[33.3,37,40.7]) * [0.50,0.55,0.84,0.92])) * (10^6/513) * (1/[0.17,0.20,0.60,0.84])
[670.4035, 1676.496, 11130.2, 25050.06]

Lampreys
There are three available estimates for completedness (Suppl. 1)
$R_{K\text{-}Pg}$ is unknown. The $R_{K\text{-}Pg}$ for cartilaginous fish was used as a surrogate.
$([N_{\text{lamprey extinctions}} \times \text{CI}]/[N_{\text{extant lampreys}} \times (\text{CI - 10\%, CI, CI}_{\text{high}})]) \times (10^6/\text{T}_{\text{obs}}) \times (1/R_{K\text{-}Pg})$
(([0.9,1,1.1] × [0.55,0.69,0.84])+[4])/([17,19,38,42] × [0.50,0.55,0.84,0.92])) × (10^6/33 yr) × (1/[0.17,0.20,0.60,0.84]) = [3729.81,6629.58,75250.11,113746.5]

Cartilaginous Fishes (no extinctions)
([502]/([17,19,38,42]*[0.5,0.55,0.84,0.92]))*(1000000/33)*(1/[0.17,0.2,0.6,0.84])
[468209.9, 793492.5, 7285777, 1.053791e+07]

Vertebrates
There are three available estimates for completedness (Suppl. 1)
$R_{K\text{-}Pg}$ = [low, med-low, med-high, high] (there are four estimates)
$([N_{\text{vertebrate extinctions}} \times \text{CI}]/[N_{\text{extant vertebrates}} \times (\text{CI - 10\%, CI, CI}_{\text{high}})]) \times (10^6/\text{T}_{\text{obs}}) \times (1/R_{K\text{-}Pg})$
((([59,65,72]*[0.39,0.704,0.976])+[6006])/([32361,35957,64283,70711]*[0.351,0.39,0.704,0.976]))*(1000000/33)*(1/[0.36,0.39,0.43,0.45])
[5882.294, 9423.117, 33534.44, 45032.65]

<u>Comparison of post-1980 extinctions to *K-Pg* extinction rate for each taxon with island endemics excluded.</u>

$([(N_{\text{taxon extinctions}} - N_{\text{taxon island extinctions}}) \times \text{CI}]/[N_{\text{extant species in taxon}} - N_{\text{extant island species in taxon}}) \times (\text{CI} \pm 10\%)]) \times (10^6/\text{T}_{\text{obs}}) \times (1/R_{K\text{-}Pg})$

Amphibians
There are three available estimates for completedness (Suppl. 1)
$R_{K\text{-}Pg}$ = [0.1, high estimate, high estimate × 1.1]
(0.1 was substituted for zero for $R_{K\text{-}Pg}$ to avoid dividing by zero)
$([(N_{\text{amphibian extinctions}} - N_{\text{amphibian island extinctions}} \times \text{CI}]/[N_{\text{extant species in Amphibia}} - N_{\text{extant island species in Amphibia}}) \times (\text{CI - 10\%, CI, CI}_{\text{high}})]) \times (10^6/\text{T}_{\text{obs}}) \times (1/R_{K\text{-}Pg})$
$(([11,12,13] \times [0.39,0.423,0.75])/(([5733,6370,6671,7338] - [988,1098,1208]) \times [0.38,0.423,0.75])) \times (10^6/33 \text{ yr}) \times (1/[0.1,0.33,0.36]) = [72,189,218,1784]$

Birds
There are three available estimates for completedness (Suppl. 1)
$R_{K\text{-}Pg}$ = [0.1, high estimate, high estimate × 1.1]
(0.1 was substituted for zero for $R_{K\text{-}Pg}$ to avoid dividing by zero)
$([N_{\text{avian extinctions}} \times \text{CI}]/[N_{\text{extant species in Aves}} \times (\text{CI - 10\%, CI, CI}_{\text{high}})]) \times (10^6/\text{T}_{\text{obs}}) \times (1/R_{K\text{-}Pg})$
$((([13,14,15] - [7.2,8,8.8]) \times [0.639,0.776,0.976])/(([8937,9930,10064,11070] - [3756,4173,4590]) \times [0.575,0.639,0.776,0.976])) \times (10^6/33 \text{ yr}) \times (1/[0.1,0.41,0.45]) = [25,75,94,923]$

Mammals
There are four available estimates for completedness (Suppl. 1)
$R_{K\text{-}Pg} = 0.33 \pm 10\%$
$([N_{\text{mammal extinctions}} \times \text{CI}]/[N_{\text{extant species in Mammalia}} \times (\text{CI - 10\%, CI, CI}_{\text{high}})]) \times (10^6/\text{T}_{\text{obs}}) \times (1/R_{K\text{-}Pg})$
$((([2.7,3,3.3] - [0]) \times [0.65,0.67,0.70,0.976])/(([4951,5501,6051] - [1366,1518,1670]) \times [0.60,0.67,0.70,0.976])) \times (10^6/33 \text{ yr}) \times (1/[0.30.33,0.36]) = [26,55,84,190]$

Reptiles
There are three available estimates for completedness (Suppl. 1)
$R_{K\text{-}Pg}$ = [0.1, high estimate, high estimate × 1.1] (there are eight estimates)
(0.1 was substituted for zero for $R_{K\text{-}Pg}$ to avoid dividing by zero)
$([N_{\text{reptile extinctions}} \times \text{CI}]/[N_{\text{extant reptiles}} \times (\text{CI - 10\%, CI, CI}_{\text{high}})]) \times (10^6/\text{T}_{\text{obs}}) \times (1/R_{K\text{-}Pg})$
$((([3.6,4,4.4] - [2.7,3,3.3]) \times [0.684,0.704,0.750,0.802])/(([3297,3663,9547,10502] - [710,789,868]) \times [0.575,0.704,0.750,0.825])) \times (10^6/33 \text{ yr}) \times (1/[0.1,0.11,0.73,0.83]) = [0.9,4,102,296]$

Bony Fishes
There are three available estimates for completedness (Suppl. 1)
$R_{K\text{-}Pg}$ = [0.1, high estimate, high estimate × 1.1] (there are eight estimates)
(0.1 was substituted for zero for $R_{K\text{-}Pg}$ to avoid dividing by zero)
$([N_{\text{Bony fish extinctions}} \times \text{CI}]/[N_{\text{extant bony fishes}} \times (\text{CI - 10\%, CI, CI}_{\text{high}})]) \times (10^6/\text{T}_{\text{obs}}) \times (1/R_{K\text{-}Pg})$
$((([28,31,34] - [0]) \times [0.55,0.69,0.84])/(([8254,9171,31193,34312] - [1897,2108,2319]) \times [0.50,0.55,0.84,0.92])) \times (10^6/33 \text{ yr}) \times (1/[0.1,0.38,0.40]) = [38,69,446,2959]$

Hagfishes (no extinctions so no calculations)

Lampreys

There are three available estimates for completedness (Suppl. 1)

$R_{K\text{-}Pg}$ is unknown. The $R_{K\text{-}Pg}$ for cartilaginous fish was used as a surrogate.

$([N_{\text{lamprey extinctions}} \times \text{CI}]/[N_{\text{extant lampreys}} \times (\text{CI - 10\%, CI, CI}_{\text{high}})]) \times (10^6/\text{T}_{\text{obs}}) \times (1/R_{K\text{-}Pg})$

$(([0.9,1,1.1] \times [0.55,0.69,0.84])/(([17,19,38,42] – [5,6,7]) \times [0.50,0.55,0.84,0.92])) \times (10^6/33 \text{ yr}) \times (1/[0.17,0.20,0.60,0.84]) = [233,648,21932,47914]$

Cartilaginous Fishes (no extinctions, no calculations)

Vertebrates

There are three available estimates for completedness (Suppl. 1)

$R_{K\text{-}Pg}$ = [low, med-low, med-high, high] (there are four estimates)

$([N_{\text{vertebrate extinctions}} \times \text{CI}]/[N_{\text{extant vertebrates}} \times (\text{CI - 10\%, CI, CI}_{\text{high}})]) \times (10^6/\text{T}_{\text{obs}}) \times (1/R_{K\text{-}Pg})$

$((([59,65,72] – [10,11,12]) \times [0.39,0.704,0.976])/(([32361,35957,64283,70711] – [9406,10451,11496]) \times [0.351,0.39,0.704,0.976])) \times (10^6/33 \text{ yr}) \times (1/[0.36,0.39,0.43,0.45]) = [21,71,297,696]$

<u>Comparison of post-1980 extinctions to *K-Pg* extinction rate for each taxon with island endemics excluded and data deficient species included.</u>

$([(N_{\text{taxon extinctions}} - N_{\text{taxon island extinctions}}) \times \text{CI}]/[N_{\text{extant species in taxon}} - N_{\text{extant island species in taxon}}) \times (\text{CI} \pm 10\%)]) \times (10^6/\text{T}_{\text{obs}}) \times (1/R_{K\text{-}Pg})$

Amphibians

There are three available estimates for completedness (Suppl. 1)

$R_{K\text{-}Pg}$ = [0.1, high estimate, high estimate × 1.1]

(0.1 was substituted for zero for $R_{K\text{-}Pg}$ to avoid dividing by zero)

$([(N_{\text{amphibian extinctions}} - N_{\text{amphibian island extinctions}} \times \text{CI}]/[N_{\text{extant species in Amphibia}} - N_{\text{extant island species in Amphibia}}) \times (\text{CI - 10\%, CI, CI}_{\text{high}})]) \times (10^6/\text{T}_{\text{obs}}) \times (1/R_{K\text{-}Pg})$

$((([1614]+[11,12,13]) \times [0.39,0.423,0.75])/(([5733,6370,6671,7338] – [988,1098,1208]) \times [0.38,0.423,0.75])) \times (10^6/33 \text{ yr}) \times (1/[0.1,0.33,0.36]) = [11197.8,26783.66,28330.28,215112.8]$

Birds

There are three available estimates for completedness (Suppl. 1)

$R_{K\text{-}Pg}$ = [0.1, high estimate, high estimate × 1.1]

(0.1 was substituted for zero for $R_{K\text{-}Pg}$ to avoid dividing by zero)

$([N_{\text{avian extinctions}} \times \text{CI}]/[N_{\text{extant species in Aves}} \times (\text{CI - 10\%, CI, CI}_{\text{high}})]) \times (10^6/\text{T}_{\text{obs}}) \times (1/R_{K\text{-}Pg})$

$(((([13,14,15] – [7.2,8,8.8])+[62]) \times [0.639,0.776,0.976])/(([8937,9930,10064,11070] - [3756,4173,4590]) \times [0.575,0.639,0.776,0.976])) \times (10^6/33 \text{ yr}) \times (1/[0.1,0.41,0.45]) = [449.08,947.24,1192.69,9170.23]$

Mammals
There are four available estimates for completedness (Suppl. 1)
$R_{K\text{-}Pg} = 0.33 \pm 10\%$
$([N_{\text{mammal extinctions}} \times \text{CI}]/[N_{\text{extant species in Mammalia}} \times (\text{CI - 10\%, CI, CI}_{\text{high}})]) \times (10^6/\text{T}_{\text{obs}}) \times (1/R_{K\text{-}Pg})$
((([2.7,3,3.3] – [0]) × [0.65,0.67,0.70,0.976])/(([4951,5501,6051] – [1366,1518,1670]) × [0.60,0.67,0.70,0.976])) × (10^6/33 yr) × (1/[0.30.33,0.36]) = [51733.38,9219.11,38457.09,66620.48]

Reptiles
There are three available estimates for completedness (Suppl. 1)
$R_{K\text{-}Pg}$ = [0.1, high estimate, high estimate × 1.1] (there are eight estimates)
(0.1 was substituted for zero for $R_{K\text{-}Pg}$ to avoid dividing by zero)
$([N_{\text{reptile extinctions}} \times \text{CI}]/[N_{\text{extant reptiles}} \times (\text{CI - 10\%, CI, CI}_{\text{high}})]) \times (10^6/\text{T}_{\text{obs}}) \times (1/R_{K\text{-}Pg})$
((([811]+[3.6,4,4.4] – [2.7,3,3.3])× [0.684,0.704,0.750,0.802])/(([3297,3663,9547,10502] – [710,789,868]) × [0.575,0.704,0.750,0.825])) × (10^6/33 yr) × (1/[0.1,0.11,0.73,0.83]) = [2506.40,3610.42,82969.53,141502]

Bony Fishes
There are three available estimates for completedness (Suppl. 1)
$R_{K\text{-}Pg}$ = [0.1, high estimate, high estimate × 1.1] (there are eight estimates)
(0.1 was substituted for zero for $R_{K\text{-}Pg}$ to avoid dividing by zero)
$([N_{\text{Bony fish extinctions}} \times \text{CI}]/[N_{\text{extant bony fishes}} \times (\text{CI - 10\%, CI, CI}_{\text{high}})]) \times (10^6/\text{T}_{\text{obs}}) \times (1/R_{K\text{-}Pg})$
((([2184]+[28,31,34] – [0]) × [0.55,0.69,0.84])/(([8254,9171,31193,34312] – [1897,2108,2319]) × [0.50,0.55,0.84,0.92])) × (10^6/33 yr) × (1/[0.1,0.38,0.40]) = [3089.18,4986.33,31388.42,190340.9]

Hagfishes (no extinctions)
((([30]-[0])*[0.55,0.69,0.84])+([8,9,10]-[6,7,8])/(([68,76,84]-[33.3,37,40.7])*[0.5,0.55,0.84,0.92]))*(10^6/33)*(1/[0.17,0.2,0.6,0.84]) = [10421.72,29145.23,187151.3,441649.9]

Lampreys
There are three available estimates for completedness (Suppl. 1)
$R_{K\text{-}Pg}$ is unknown. The $R_{K\text{-}Pg}$ for cartilaginous fish was used as a surrogate.
$([N_{\text{lamprey extinctions}} \times \text{CI}]/[N_{\text{extant lampreys}} \times (\text{CI - 10\%, CI, CI}_{\text{high}})]) \times (10^6/\text{T}_{\text{obs}}) \times (1/R_{K\text{-}Pg})$
(([4]+[0.9,1,1.1] × [0.55,0.69,0.84])/(([17,19,38,42] – [5,6,7]) × [0.50,0.55,0.84,0.92])) × (10^6/33 yr) × (1/[0.17,0.20,0.60,0.84]) = [202.45,7647.16,115490.6,260249.6]

Cartilaginous Fishes (no extinctions)
((([502]*[0.55,0.69,0.84])+([163.8,182,200.2]-[110.7,123,135.3]))/(([983.7,1093,1202.3]-[649.8,722,794.2])*[0.5,0.55,0.84,0.92]))*(10^6/33)*(1/[0.17,0.2,0.6,0.84])
[21598.53, 65640.84, 301266.8, 962472.8]

Vertebrates
There are three available estimates for completedness (Suppl. 1)
$R_{K\text{-}Pg}$ = [low, med-low, med-high, high] (there are four estimates)
$([N_{\text{vertebrate extinctions}} \times \text{CI}]/[N_{\text{extant vertebrates}} \times (\text{CI - 10\%, CI, CI}_{\text{high}})]) \times (10^6/\text{T}_{\text{obs}}) \times (1/R_{K\text{-}Pg})$
((([6006]+[59,65,72] – [10,11,12]) × [0.39,0.704,0.976])/(([32361,35957,64283,70711] – [9406,10451,11496]) × [0.351,0.39,0.704,0.976])) × (10^6/33 yr) × (1/[0.36,0.39,0.43,0.45]) = [7445.18,17568.68,73804.29,138293]

Comparison of post-1980 extinctions to *K-Pg* extinction rate for each taxon with island endemics, impaired species, and data deficient species included.

$([(N_{\text{taxon extinctions}} + N_{\text{taxon impaired species}} + \text{DD}) \times \text{CI}]/[N_{\text{extant species in taxon}}] \times (\text{CI} \pm 10\%)]) \times (10^6/\text{T}_{\text{obs}}) \times (1/R_{K\text{-}Pg})$

Amphibians
There are three available estimates for completedness (Suppl. 1)
$R_{K\text{-}Pg}$ = [0.1, high estimate, high estimate × 1.1]
(0.1 was substituted for zero for $R_{K\text{-}Pg}$ to avoid dividing by zero)
$([(N_{\text{amphibian extinctions}} + N_{\text{impaired amphibians)}} \times \text{CI}]/[N_{\text{extant species in Amphibia}}) \times (\text{CI - 10\%, CI, CI}_{\text{high}})]) \times (10^6/\text{T}_{\text{obs}}) \times (1/R_{K\text{-}Pg})$
((([1614]+[11,12,13]+[1737.9,1931,2124.1]) * [0.39,0.423,0.75])/([5733,6370,6671,7338] * [0.38,0.423,0.75])) * (10^6/33) * (1/[0.1,0.33,0.36])
[20056.65, 48955.78, 51283.5, 391379.8]

Birds
There are three available estimates for completedness (Suppl. 1)
$R_{K\text{-}Pg}$ = [0.1, high estimate, high estimate × 1.1]
(0.1 was substituted for zero for $R_{K\text{-}Pg}$ to avoid dividing by zero)
$([(N_{\text{avian extinctions}} + N_{\text{impaired birds)}}) \times \text{CI}]/[N_{\text{extant species in Aves}} \times (\text{CI - 10\%, CI, CI}_{\text{high}})]) \times (10^6/\text{T}_{\text{obs}}) \times (1/R_{K\text{-}Pg})$
((([62]+[13,14,15]+[1061.1,1179,1296.9]) * [0.639,0.776,0.976])/([8937,9930,10064,11070] * [0.575,0.639,0.776,0.976])) * (10^6/33) * (1/[0.1,0.41,0.45]) =
[4522.747, 9213.024, 11348.3, 79102.36]

Mammals
There are four available estimates for completedness (Suppl. 1)
$R_{K\text{-}Pg}$ = 0.33 ± 10%
$([(N_{\text{mammal extinctions}} + N_{\text{impaired mammals}} + \text{DD}) \times \text{CI}]/[N_{\text{extant species in Mammalia}} \times (\text{CI - 10\%, CI, CI}_{\text{high}})]) \times (10^6/\text{T}_{\text{obs}}) \times (1/R_{K\text{-}Pg})$
((([799]+[2.7,3,3.3]+[1026,1140,1254]) * [0.639,0.776,0.976])/([4950.9,5501,6051.1] * [0.6,0.67,0.7,0.825])) * (10^6/33) * (1/[0.3,0.33,0.36]) =
[19687.12, 35927.87, 37555.93, 68260.79]

Reptiles

There are three available estimates for completedness (Suppl. 1)

$R_{K\text{-}Pg}$ = [0.1, high estimate, high estimate × 1.1] (there are eight estimates)

(0.1 was substituted for zero for $R_{K\text{-}Pg}$ to avoid dividing by zero)

$([(N_{\text{reptile extinctions}} + \text{N}_{\text{impaired reptiles}}) \times \text{CI}]/[N_{\text{extant reptiles}} \times (\text{CI - 10\%, CI, CI}_{\text{high}})]) \times (10^6/\text{T}_{\text{obs}}) \times (1/R_{K\text{-}Pg})$

((([811]+[3.6,4,4.4]+[802]) * [0.684,0.704,0.75,0.802])/([3297,3663,9547,10502] * [0.575,0.704,0.75,0.825])) * (10^6/33) * (1/[0.1,0.11,0.73,0.83]) =
[4656.632, 6595.519, 129635.4, 207472.1]

Bony Fishes

There are three available estimates for completedness (Suppl. 1)

$R_{K\text{-}Pg}$ = [0.1, high estimate, high estimate × 1.1] (there are eight estimates)

(0.1 was substituted for zero for $R_{K\text{-}Pg}$ to avoid dividing by zero)

$([N_{\text{bony fish extinctions}} + N_{\text{impaired bony fishes}}) \times \text{CI}]/[N_{\text{extant bony fishes}} \times (\text{CI - 10\%, CI, CI}_{\text{high}})]) \times (10^6/\text{T}_{\text{obs}}) \times (1/R_{K\text{-}Pg})$

((([2184]+[28,31,34]+[1743.3,1937,2130.7]) * [0.55,0.69,0.84])/([8254,9171,31193,34312] * [0.5,0.55,0.84,0.92])) * (10^6/33) * (1/[0.1,0.38,0.40]) =
[5220.107, 8718.066, 45298.3, 268250.4]

Hagfishes

There are three available estimates for completedness (Suppl. 1)

$R_{K\text{-}Pg}$ is unknown. The $R_{K\text{-}Pg}$ for cartilaginous fish was used as a surrogate.

$([N_{\text{hagfish extinctions}} + N_{\text{impaired hagfishes}}) \times \text{CI}]/[N_{\text{extant hagfishes}} \times (\text{CI - 10\%, CI, CI}_{\text{high}})]) \times (10^6/\text{T}_{\text{obs}}) \times (1/R_{K\text{-}Pg})$

((([30]+[0]+[8.1,9,9.9]) * [0.55,0.69,0.84])/([68,76,84] * [0.5,0.55,0.84,0.92])) * (10^6/33) * (1/[0.17,0.2,0.6,0.84]) = [8369.893, 18286.72, 111298.4, 199937.1]

Lampreys

There are three available estimates for completedness (Suppl. 1)

$R_{K\text{-}Pg}$ is unknown. The $R_{K\text{-}Pg}$ for cartilaginous fish was used as a surrogate.

$([N_{\text{reptile extinctions}} + \text{N}_{\text{impaired lampreys}}) \times \text{CI}]/[N_{\text{extant lampreys}} \times (\text{CI - 10\%, CI, CI}_{\text{high}})]) \times (10^6/\text{T}_{\text{obs}}) \times (1/R_{K\text{-}Pg})$

((([0.9,1,1.1]+[2,3,4]+[3.6,4,4.4]) * [0.55,0.69,0.84])/([17,19,38,42] * [0.5,0.55,0.84,0.92])) * (10^6/33) * (1/[0.17,0.2,0.6,0.84]) = [3337.687, 8733.956, 80034.8, 167348.3]

Cartilaginous Fishes

There are three available estimates for completedness (Suppl. 1)

$R_{K\text{-}Pg}$ is unknown. The $R_{K\text{-}Pg}$ for cartilaginous fish was used as a surrogate.

$([N_{\text{cartilaginous fish extinctions}} + N_{\text{impaired cartilaginous fishes}}) \times \text{CI}]/[N_{\text{extant cartilaginous fishes}} \times (\text{CI - 10\%, CI, CI}_{\text{high}})]) \times (10^6/\text{T}_{\text{obs}}) \times (1/R_{K\text{-}Pg})$

((([0]+[502]+[163.8,182,200.2]) * [0.55,0.69,0.84])/([984,1093,1202] * [0.5,0.55,0.84,0.92])) * (10^6/33) * (1/[0.17,0.2,0.6,0.84]) = [11928.01, 25924.18, 119127.8, 214008.1]

Vertebrates

There are three available estimates for completedness (Suppl. 1)

$R_{K\text{-}Pg}$ = [low, med-low, med-high, high] (there are four estimates)

$([N_{\text{vertebrate extinctions}} + N_{\text{impaired vertebrates}}) \times \text{CI}]/[N_{\text{extant vertebrates}} \times (\text{CI - 10\%, CI, CI}_{\text{high}})]) \times (10^6/T_{\text{obs}}) \times (1/R_{K\text{-}Pg})$

((([6006]+[58.5,65,71.5]+[163.8,182,200.2]) * [0.39,0.704,0.976])/([32361,35957,64283,70711] * [0.39,0.704,0.976])) * (10^6/33) * (1/[0.36,0.39,0.43,0.45]) =

[2369.932, 6854.49, 13513.3, 40867.87]

<u>Comparison of post-1500 extinctions to *K-Pg* extinction rate for each taxon with island endemics excluded and impaired species included.</u>

$([((N_{\text{taxon extinctions}} - N_{\text{taxon island extinctions}}) + (N_{\text{impaired species}} - N_{\text{impaired island species}})) \times \text{CI}]/[N_{\text{extant species in taxon}} - N_{\text{extant island species in taxon}}) \times (\text{CI} \pm 10\%)]) \times (10^6/T_{\text{obs}}) \times (1/R_{K\text{-}Pg})$

Amphibians

There are three available estimates for completedness (Suppl. 1)

$R_{K\text{-}Pg}$ = [0.1, high estimate, high estimate × 1.1]

(0.1 was substituted for zero for $R_{K\text{-}Pg}$ to avoid dividing by zero)

$([((N_{\text{amphibian extinctions}} - N_{\text{island amphibian extinctions}}) + (N_{\text{impaired amphibians}} - N_{\text{island impaired amphibians}}) \times \text{CI}]/([N_{\text{extant species in Amphibia}}] - [N_{\text{extant island amphibians}}]) \times (\text{CI - 10\%, CI, CI}_{\text{high}})]) \times (10^6/T_{\text{obs}}) \times (1/R_{K\text{-}Pg})$

(((([13,14,15] − [0])+ ([1738,1931,2124] − [304,338,372]) × [0.39,0.423,0.75])/(([5733,6370,6671,7338] − [988,1098,1208]) × [0.38,0.423,0.75])) × (10^6/33 yr) × (1/[0.1,0.33,0.36]) = [9502,26471,27999,242605]

Birds

There are three available estimates for completedness (Suppl. 1)

$R_{K\text{-}Pg}$ = [0.1, high estimate, high estimate × 1.1]

(0.1 was substituted for zero for $R_{K\text{-}Pg}$ to avoid dividing by zero)

$([((N_{\text{avian extinctions}} - N_{\text{island avian extinctions}}) + (N_{\text{impaired avians}} - N_{\text{island impaired avians}}) \times \text{CI}]/([N_{\text{extant species in Avia}}] - [N_{\text{extant island avians}}]) \times (\text{CI - 10\%, CI, CI}_{\text{high}})]) \times (10^6/T_{\text{obs}}) \times (1/R_{K\text{-}Pg})$

(((([13,14,15] – [7.2,8,8.8]) + ([1067,1179,1297] – [494,549,604]) × [0.639,0.776,0.976])/(([8937,9930,10064,11070] – [3756,4173,5490]) × [0.575,0.639,0.776,0.976])) × (10^6/33 yr) × (1/[0.1,0.41,0.45]) = 2816,7979,9916,120988]

Mammals

There are four available estimates for completedness (Suppl. 1)

$R_{K\text{-}Pg} = 0.33 \pm 10\%$

$([((N_{\text{mammalian extinctions}} - N_{\text{island mammal extinctions}}) + (N_{\text{impaired mammals}} - N_{\text{island impaired mammals}}) \times \text{CI}]/([N_{\text{extant species in Mammalia}}] - [N_{\text{extant island mammals}}]) \times (\text{CI - 10\%, CI, CI}_{\text{high}})]) \times (10^6/T_{\text{obs}}) \times (1/R_{K\text{-}Pg})$

(((([2.7,3,3.3] – [0]) + ([1026,1140,1254]-[365,405,446])) × [0.65,0.67,0.70,0.976])/(([4951,5501,6051]-[1366,1518,1670]) × [0.60,0.67,0.70,0.976])) × (10^6/33 yr) × (1/[0.30,0.33,0.36]) = [6966,16274,17788,44711]

Reptiles

There are three available estimates for completedness (Suppl. 1)

$R_{K\text{-}Pg}$ = [0.1, high estimate, high estimate × 1.1] (there are eight estimates)

(0.1 was substituted for zero for $R_{K\text{-}Pg}$ to avoid dividing by zero)

$([((N_{\text{reptile extinctions}} - N_{\text{island reptile extinctions}}) + (N_{\text{impaired reptiles}} - N_{\text{island impaired reptiles}}) \times \text{CI}]/([N_{\text{extant species in Reptilia}}] - [N_{\text{extant island reptiles}}]) \times (\text{CI - 10\%, CI, CI}_{\text{high}})]) \times (10^6/\text{T}_{\text{obs}}) \times (1/R_{K\text{-}Pg})$

(((([3.6,4,4.4] – [2.7,3,3.3]) + ([722,802,882] – [253,281,309]))× [0.684,0.704,0.750,0.802])/(([3297,3663,9547,10502] – [710,789,868]) × [0.575,0.704,0.750,0.825])) × (10^6/33 yr) × (1/[0.1,0.11,0.73,0.83]) = [1278,2322,53305,109746]

Bony Fishes

There are three available estimates for completedness (Suppl. 1)

$R_{K\text{-}Pg}$ = [0.1, high estimate, high estimate × 1.1] (there are eight estimates)

(0.1 was substituted for zero for $R_{K\text{-}Pg}$ to avoid dividing by zero)

$([((N_{\text{bony fish extinctions}} - N_{\text{island bony fish extinctions}}) + (N_{\text{impaired impaired bony fishes}} - N_{\text{island impaired bony fishes}}) \times \text{CI}]/([N_{\text{extant bony fishes}}] - [N_{\text{extant island bony fishes}}]) \times (\text{CI - 10\%, CI, CI}_{\text{high}})]) \times (10^6/\text{T}_{\text{obs}}) \times (1/R_{K\text{-}Pg})$

(((([27,31,34] – [0]) + ([1743,1937,2131]-[217,241,265])) × [0.55,0.69,0.84])/(([8254,9171,31193,34312]-[1897,2108,2319])× [0.50,0.55,0.84,0.92])) × (10^6/33 yr) × (1/[0.1,0.38,0.40]) = [2102,3888,24469,167138]

Hagfishes

There are three available estimates for completedness (Suppl. 1)

$([((N_{\text{hagfish extinctions}} - N_{\text{island hagfish extinctions}}) + (N_{\text{impaired hagfishes}} - N_{\text{island impaired hagfishes}}) \times \text{CI}]/([N_{\text{extant hagfishes}}] - [N_{\text{extant island hagfishes}}]) \times (\text{CI - 10\%, CI, CI}_{\text{high}})]) \times (10^6/\text{T}_{\text{obs}}) \times (1/R_{K\text{-}Pg})$

((([8,9,10]-[6,7,8]) × [0.55,0.69,0.84])/(([68,76,84]-[33,37,41]) × [0.50,0.55,0.84,0.92])) × (10^6/33 yr) × (1/[0.17,0.20,0.60,0.84]) = [-11091,1064,14622,55457]

Lampreys

There are three available estimates for completedness (Suppl. 1)

$R_{K\text{-}Pg}$ is unknown. The $R_{K\text{-}Pg}$ for cartilaginous fish was used as a surrogate.

$([((N_{\text{lamprey extinctions}} - N_{\text{island lamprey extinctions}}) + (N_{\text{impaired lampreys}} - N_{\text{island impaired lampreys}}) \times \text{CI}]/([N_{\text{extant lampreys}}] - [N_{\text{extant island lampreys}}]) \times (\text{CI - 10\%, CI, CI}_{\text{high}})]) \times (10^6/\text{T}_{\text{obs}}) \times (1/R_{K\text{-}Pg})$

(((([0.9,1,1.1]-[0]) + ([2,3,4]-[0.9,1,1.1])) × ([0.55,0.69,0.84]))/(([17,19,38,42]-[5,6,7]) × [0.50,0.55,0.84,0.92])) × (10^6/33 yr) × (1/[0.17,0.20,0.60,0.84]) = [758,3241,51176,140749]

Cartilaginous Fishes

There are three available estimates for completedness (Suppl. 1)

$R_{K\text{-}Pg}$ is unknown. The $R_{K\text{-}Pg}$ for cartilaginous fish was used as a surrogate.

$([((N_{\text{cartilaginous fish extinctions}} - N_{\text{island cartilaginous fish extinctions}}) + (N_{\text{impaired cartilaginous fishes}} - N_{\text{island impaired cartilaginous fishes}}) \times \text{CI}]/([N_{\text{extant cartilaginous fishes}}] - [N_{\text{extant island cartilaginous fishes}}]) \times (\text{CI - 10\%, CI, CI}_{\text{high}})]) \times (10^6/\text{T}_{\text{obs}}) \times (1/R_{K\text{-}Pg})$

((([164,182,200]-[111,123,135]) × [0.55,0.69,0.84])/(([984,1093,1202]-[650,722,794]) × [0.50,0.55,0.84,0.92])) × (10^6/33 yr) × (1/[0.17,0.20,0.60,0.84]) = [1094,6486,30741,141852]

Vertebrates

There are three available estimates for completedness (Suppl. 1)

$R_{K\text{-}Pg}$ = [low, med-low, med-high, high] (there are four estimates)

$([((N_{\text{vertebrate extinctions}} - N_{\text{island vertebrate extinctions}}) + (N_{\text{impaired vertebrates}} - N_{\text{island impaired vertebrates}}) \times \text{CI}]/([N_{\text{extant species in Vertebrata}}] - [N_{\text{extant island vertebrates}}]) \times (\text{CI - 10\%, CI, CI}_{\text{high}})]) \times (10^6/\text{T}_{\text{obs}}) \times (1/R_{K\text{-}Pg})$

((((57,65,72]-[10,11,12]) + ([6504,7227,7950]-[1841,2045,2250])) × [0.39,0.704,0.976])/(([32361,35957,64283,70711]-[9406,10451,11496]) × [0.351,0.39,0.704,0.976])) × (10^6/33 yr) × (1/[0.36,0.39,0.43,0.45]) = [1887,6855,28793,69225]

<u>Comparison of post-1500 extinctions to *K-Pg* extinction rate for each taxon with island endemics excluded and impaired species included.</u>

$([((N_{\text{taxon extinctions}} - N_{\text{taxon island extinctions}}) + (\text{N}_{\text{impaired species}} - \text{N}_{\text{impaired island species}})) \times \text{CI}]/[N_{\text{extant species in taxon}} - N_{\text{extant island species in taxon}}) \times (\text{CI} \pm 10\%)]) \times (10^6/\text{T}_{\text{obs}}) \times (1/R_{K\text{-}Pg})$

Amphibians

There are three available estimates for completedness (Suppl. 1)

$R_{K\text{-}Pg}$ = [0.1, high estimate, high estimate × 1.1]

(0.1 was substituted for zero for $R_{K\text{-}Pg}$ to avoid dividing by zero)

$([((N_{\text{amphibian extinctions}} + \text{DD} - N_{\text{island amphibian extinctions}}) + (N_{\text{impaired amphibians}} - N_{\text{island impaired amphibians}}) \times \text{CI}]/([N_{\text{extant species in Amphibia}}] - [N_{\text{extant island amphibians}}]) \times (\text{CI - 10\%, CI, CI}_{\text{high}})]) \times (10^6/\text{T}_{\text{obs}}) \times (1/R_{K\text{-}Pg})$

((([1614]+[11,12,13]+[1737.9,1931,2124.1]-[0]-[304.2,338,371.8]) * [0.39,0.423,0.75])/([5733,6370,6671,7338]-[988.2,1098,1207.8]) * [0.39,0.423,0.75]) * (10^6/33) * (1/[0.1,0.33,0.36]) = [6028.904, 9487.457, 10035.37, 129875]

Birds

There are three available estimates for completedness (Suppl. 1)

$R_{K\text{-}Pg}$ = [0.1, high estimate, high estimate × 1.1]

(0.1 was substituted for zero for $R_{K\text{-}Pg}$ to avoid dividing by zero)

$([((N_{\text{avian extinctions}} + \text{DD} - N_{\text{island avian extinctions}}) + (N_{\text{impaired avians}} - N_{\text{island impaired avians}}) \times \text{CI}]/([N_{\text{extant species in Avia}}] - [N_{\text{extant island avians}}]) \times (\text{CI - 10\%, CI, CI}_{\text{high}})]) \times (10^6/\text{T}_{\text{obs}}) \times (1/R_{K\text{-}Pg})$

((([62]+[13,14,15]+[1061.1,1179,1296.9]-[494.1,549,604.01]) * [0.639,0.776,0.976])/(([8937,9930,10064,11070] - [3756,4173,4590]) * [0.575,0.639,0.776,0.976])) * (10^6/33) * (1/[0.1,0.41,0.45]) = [4522.747, 9213.024, 11348.3, 79102.36]

Mammals

There are four available estimates for completedness (Suppl. 1)

$R_{K\text{-}Pg}$ = 0.33 ± 10%

$([((N_{\text{mammalian extinctions}} - N_{\text{island mammal extinctions}}) + (N_{\text{impaired mammals}} - N_{\text{island impaired mammals}}) \times \text{CI}]/([N_{\text{extant species in Mammalia}}] - [N_{\text{extant island mammals}}]) \times (\text{CI - 10\%, CI, CI}_{\text{high}})]) \times (10^6/\text{T}_{\text{obs}}) \times (1/R_{K\text{-}Pg})$

((([799]+[2.7,3,3.3]+[1026,1140,1254]-[0]-[364.5,405,445.5]) * [0.639,0.776,0.976])/([4950.9,5501,6051.1]-[1366.2,1518,1669.8]) * [0.639,0.776,0.976]) * (10^6/33) * (1/[0.3,0.33,0.36]) = [10133.08, 21324.38, 21352.15, 49642.16]

Reptiles

There are three available estimates for completedness (Suppl. 1)

$R_{K\text{-}Pg}$ = [0.1, high estimate, high estimate × 1.1] (there are eight estimates)

(0.1 was substituted for zero for $R_{K\text{-}Pg}$ to avoid dividing by zero)

$([((N_{\text{reptile extinctions}} + \text{DD} - N_{\text{island reptile extinctions}}) + (N_{\text{impaired reptiles}} - N_{\text{island impaired reptiles}}) \times \text{CI}]/([N_{\text{extant species in Reptilia}}] - [N_{\text{extant island reptiles}}]) \times (\text{CI - 10\%, CI, CI}_{\text{high}})]) \times (10^6/\text{T}_{\text{obs}}) \times (1/R_{K\text{-}Pg})$

((([811]+[3.6,4,4.4]+[721.8,802,882.2]-[252.9,281,309.1]-[2.7,3,3.3]) * [0.684,0.704,0.75,0.802])/([3297,3663,9547,10502]-[710,789,868]) * [0.684,0.704,0.75,0.802]) * (10^6/33) * (1/[0.1,0.11,0.73,0.83]) = [2134.286, 3130.19, 71898.89, 115750.6]

Bony Fishes

There are three available estimates for completedness (Suppl. 1)

$R_{K\text{-}Pg}$ = [0.1, high estimate, high estimate × 1.1] (there are eight estimates)

(0.1 was substituted for zero for $R_{K\text{-}Pg}$ to avoid dividing by zero)

$([((N_{\text{bony fish extinctions}} + \text{DD} - N_{\text{island bony fish extinctions}}) + (N_{\text{impaired impaired bony fishes}} - N_{\text{island impaired bony fishes}}) \times \text{CI}]/([N_{\text{extant bony fishes}}] - [N_{\text{extant island bony fishes}}]) \times (\text{CI - 10\%, CI, CI}_{\text{high}})]) \times (10^6/\text{T}_{\text{obs}}) \times (1/R_{K\text{-}Pg})$

((([2184]+[28,31,34]+[1743,1937,2130.7]-[216.9,241,265.1]-[0]) * [0.55,0.69,0.84])/(([8254,9171,31193,34312]-[1897.2,2108,2318.8]) * [0.55,0.69,0.84])) * (10^6/33) * (1/[0.1,0.38,0.4]) = [5644.987, 10720.37, 44168.45, 322264]

Hagfishes

There are three available estimates for completedness (Suppl. 1)

$([((N_{\text{hagfish extinctions}} - N_{\text{island hagfish extinctions}}) + (N_{\text{impaired hagfishes}} + \text{DD} - N_{\text{island impaired hagfishes}}) \times \text{CI}]/([N_{\text{extant hagfishes}}] - [N_{\text{extant island hagfishes}}]) \times (\text{CI - 10\%, CI, CI}_{\text{high}})]) \times (10^6/\text{T}_{\text{obs}}) \times (1/R_{K\text{-}Pg})$

((([30]+[0]+[8.1,9,9.9]-[6.3,7,7.7]-[0]) * [0.5,0.69,0.92])/(([68,76,84]-[33.3,37,40.7]) * [0.5,0.69,0.92])) * (10^6/33) * (1/[0.17,0.2,0.6,0.84]) =
[9435.628, 33670.03, 147630.2, 475759.6]

Lampreys

There are three available estimates for completedness (Suppl. 1)

$R_{K\text{-}Pg}$ is unknown. The $R_{K\text{-}Pg}$ for cartilaginous fish was used as a surrogate.

$([((N_{\text{lamprey extinctions}} - N_{\text{island lamprey extinctions}}) + (N_{\text{impaired lampreys}} - N_{\text{island impaired lampreys}}) \times \text{CI}]/([N_{\text{extant lampreys}}] - [N_{\text{extant island lampreys}}]) \times (\text{CI - 10\%, CI, CI}_{\text{high}})]) \times (10^6/\text{T}_{\text{obs}}) \times (1/R_{K\text{-}Pg})$

((([4]+[.9,1,1.1]+[2,3,4]-[.9,1,1.1]-[0]) * [0.5,0.55,0.84,0.92])/(([17,19,38,42]-[5,6,7]) * [0.5,0.55,0.84,0.92])) * (10^6/33) * (1/[0.17,0.2,0.6,0.84]) = [2014, 6200,142403,40868]

Cartilaginous Fishes
There are three available estimates for completedness (Suppl. 1)
$R_{K\text{-}Pg}$ is unknown. The $R_{K\text{-}Pg}$ for cartilaginous fish was used as a surrogate.
$([((N_{\text{cartilaginous fish extinctions}} + \text{DD} - N_{\text{island cartilaginous fish extinctions}}) + (N_{\text{impaired cartilaginous fishes}} - N_{\text{island impaired cartilaginous fishes}}) \times \text{CI}]/([N_{\text{extant cartilaginous fishes}}] - [N_{\text{extant island cartilaginous fishes}}]) \times (\text{CI - 10\%, CI, CI}_{\text{high}})]) \times (10^6/\text{T}_{\text{obs}}) \times (1/R_{K\text{-}Pg})$
((([502]+[0]+[163.8,182,200.2]-[110.7,123,135.3]-[9.9,11,12.1]) * [0.55,0.69,0.84])/(([983.7,1093,1202.3]-[649.8,722,794.2]) * [0.55,0.69,0.84])) * (10^6/33) * (1/[0.17,0.2,0.6,0.84]) = [22119.95, 74736.58, 225026.6, 836979.9]]

Vertebrates
There are three available estimates for completedness (Suppl. 1)
$R_{K\text{-}Pg}$ = [low, med-low, med-high, high] (there are four estimates)
$([((N_{\text{vertebrate extinctions}} - N_{\text{island vertebrate extinctions}}) + (N_{\text{impaired vertebrates}} - N_{\text{island impaired vertebrates}}) \times \text{CI}]/([N_{\text{extant species in Vertebrata}}] - [N_{\text{extant island vertebrates}}]) \times (\text{CI - 10\%, CI, CI}_{\text{high}})]) \times (10^6/\text{T}_{\text{obs}}) \times (1/R_{K\text{-}Pg})$
((([6006]+[58.5,65,71.5]+[1840.5,2045,2248.5]-[2045]-[9.9,11,12.1]) * [0.39,0.704,0.976])/(([32361,35957,64283,70711]-[9405.9,10451,11496.1]) * [0.39,0.704,0.976])) * (10^6/33) * (1/[0.36,0.39,0.43,0.45]) =
[2566.358, 7931.914, 18463.9, 63323.58]

<u>Minimum post-1500 magnitude of extinction predicted per million years for each taxon.</u>

$(N_{\text{recent taxon extinctions}}/513 \text{ years}) \times 10^6$

Amphibians
$(N_{\text{Amphibian extinctions}}/513 \text{ years}) \times (10^6) =$
$([34,38,42]/513) \times (10^6) =$ [66277,74074,81871] extinctions in 1 MY

Birds
$(N_{\text{Avian extinctions}}/513 \text{ years}) \times (10^6) =$
$([121,134,147]/513) \times (10^6) =$ [235867,261209,286550] extinctions in 1 MY

Mammals
$(N_{\text{mammal extinctions}}/513 \text{ years}) \times (10^6) =$
$([71,79,87]/513) \times (10^6) =$ [138402,153996,169591] extinctions in 1 MY

Reptiles
$(N_{\text{Reptile extinctions}}/513 \text{ years}) \times (10^6) =$
$([20,22,24]/513) \times (10^6) =$ [38986,42885,46784] extinctions in 1 MY

Bony Fishes
$(N_{\text{bony fish extinctions}}/513 \text{ years}) \times (10^6) =$
$([59,66,73]/513) \times (10^6) =$ [115010,128655,142300] extinctions in 1 MY

Hagfishes
($N_{\text{hagfish extinctions}}$/513 years) × ($10^6$) =
([0]/513) × (10^6) = [0] extinctions in 1 MY

Lampreys
($N_{\text{hagfish extinctions}}$/513 years) × ($10^6$) =
([0.9,1,1.1]/513) × (10^6) = [1754,1949,2144] extinctions in 1 MY

Cartilaginous Fishes
($N_{\text{cartilaginous fish extinctions}}$/513 years) × ($10^6$) =
([0]/513) × (10^6) = [0] extinctions in 1 MY

Vertebrates
($N_{\text{cartilaginous fish extinctions}}$/513 years) × ($10^6$) =
([306,340,374]/513) × (10^6) = [596491,662768,729045] extinctions in 1 MY

<u>Minimum post-1980 magnitude of extinction predicted per million years for each taxon.</u>

($N_{\text{recent taxon extinctions}}$/33 years) × 10^6

Amphibians
($N_{\text{Amphibian extinctions}}$/33 years) × ($10^6$) =
([11,12,13]/33) × (10^6) = [333333,363636,393939] extinctions in 1 MY

Birds
($N_{\text{Avian extinctions}}$/33 years) × ($10^6$) =
([13,14,15]/33) × (10^6) = [393939,424242,454546] extinctions in 1 MY

Mammals
($N_{\text{mammal extinctions}}$/33 years) × ($10^6$) =
([2.7,3,3.3]/33) × (10^6) = [81818,90909,100000] extinctions in 1 MY

Reptiles
($N_{\text{Reptile extinctions}}$/33 years) × ($10^6$) =
([3.6,4,4.4]/513) × (10^6) = [109091,121212,133333] extinctions in 1 MY

Bony Fishes
($N_{\text{bony fish extinctions}}$/33 years) × ($10^6$) =
([28,31,34]/513) × (10^6) = [848485,939394,1030304] extinctions in 1 MY

Hagfishes
($N_{\text{hagfish extinctions}}$/33 years) × ($10^6$) =
([0]/513) × (10^6) = [0] extinctions in 1 MY

Lampreys
$(N_{\text{hagfish extinctions}}/33 \text{ years}) \times (10^6) =$
$([0.9,1,1.1]/33) \times (10^6) = [27273,30303,33333]$ extinctions in 1 MY

Cartilaginous Fishes
$(N_{\text{cartilaginous fish extinctions}}/33 \text{ years}) \times (10^6) =$
$([0]/33) \times (10^6) = [0]$ extinctions in 1 MY

Vertebrates
$(N_{\text{cartilaginous fish extinctions}}/33 \text{ years}) \times (10^6) =$
$([59,65,72]/33) \times (10^6) = [1787878,1969696,2181819]$ extinctions in 1 MY

<u>Years until total extinction for each taxon based on post-1500 extinction rate.</u>

$(N_{\text{extant taxon species}} \times 513 \text{ years})/ N_{\text{recent taxon extinctions}}$

Amphibians
(([5733,6370,6671,7338]*513)/[34,38,42]) = [70025, 85995, 90059, 110718] years

Birds
(([8937,9930,10064,11070]*513)/[121,134,147]) = [31188, 38016, 38529, 46933] years

Mammals
(([4951,5501,6051]*513)/[71,79,87]) = [29194, 35722, 43721] years

Reptiles
(([3297,3663,9547,10502]*513)/[20,22,24]) = [70473, 85415, 222619, 269376] years

Bony Fishes
(([8254,9171,31193,34312]*513)/[59,66,73]) = [58004, 71284, 242455, 298340] years

Hagfishes
(([68,76,84]*513)/[0]) = empty set/undefined

Lampreys
(([17,19,38,42]*513)/[0.9,1,1.1]) = [7928, 9747, 19494, 23940] years

Cartilaginous Fishes
(([984,1093,1202]*513)/[0]) = empty set/undefined

Vertebrates
(([32361,35957,64283,70711]*513)/[306,340,374]) = [44388, 54253, 96992, 118545] years

Years until total extinction for each taxon based on post-1500 extinction rate excluding island species.

($N_{\text{extant taxon species}}$ × 513 years)/ $N_{\text{recent taxon extinctions}}$

Amphibians
((([5733,6370,6671,7338]-[988,1098,1208])*513)/([34,38,42]-[0])) = [54619, 70248, 76239, 97240] years

Birds (the +10% estimate for island extinctions was reduced from 132 to 120 to avoid dividing by zero).
((([8937,9930,10064,11070]-[3756,4173,4590])*513)/([121,134,147]-[108,120,120])) = [57180, 210953, 215863, 3752082] years

Mammals
((([4951,5501,6051]-[1366,1518,1670])*513)/([71,79,87]-[32,36,40])) = [30603,47518,77529] years

Reptiles (The +10% estimate for island extinctions was reduced from 20 to 19 to avoid dividing by zero).
((([3297,3663,9547,10502]-[710,789,868])*513)/([20,22,24]-[16,18,19])) = [70473, 85415, 222619, 269376] years

Bony Fishes
((([8254,9171,31193,34312]-[1897,2108,2319])*513)/([59,66,73]-[1.8,2,2.2])) = [42762, 56614, 233135, 292762] years

Hagfishes
((([68,76,84])*513)/([0]) = empty set/undefined

Lampreys
((([17,19,38,42]-[5.4,6,6.6])*513)/([0.9,1,1.1]-[0])) = [3334, 4446, 32832, 46940] years

Cartilaginous Fishes
(([984,1093,1202]*513)/[0]) = empty set/undefined

Vertebrates
((([32361,35957,64283,70711]-[9406,10451,11497])*513)/([306,340,374]-[158,176,194])) = [49552, 79784, 168389, 280799] years

Years until total extinction for each taxon based on post-1980 extinction rate.

($N_{\text{extant taxon species}}$ × 33 years)/ $N_{\text{recent taxon extinctions}}$

Amphibians
((([5733,6370,6671,7338]*33)/[11,12,13]) = [14553, 17517.5, 18345.25, 22014] years

Birds
((([8937,9930,10064,11070]*33)/[13,14,15]) = [19661, 23406, 23722, 28101] years

Mammals
((([4951,5501,6051]*33)/[2.7,3,3.3]) = [49510, 60511, 73957] years

Reptiles
((([3297,3663,9547,10502]*33)/[3.6,4.4.4]) = [24727, 30220, 78763, 96268]years

Bony Fishes
((([8254,9171,31193,34312]*33)/[28,31,34]) = [8011, 9763, 33205, 40439] years

Hagfishes
((([68,76,84]*33)/[0]) = empty set/undefined

Lampreys
((([17,19,38,42]*33)/[0.9,1,1.1]) = [510, 627, 1254, 1540] years

Cartilaginous Fishes
((([984,1093,1202]*33)/[0]) = empty set/undefined

Vertebrates
((([32361,35957,64283,70711]*33)/[59,65,72]) = [44388, 54253, 96992, 118545] years
[14832, 18255, 32636, 39550]

<u>Years until total extinction for each taxon based on post-1980 extinction rate excluding island species.</u>

($N_{\text{extant taxon species}}$ × 33 years)/ $N_{\text{recent taxon extinctions}}$

Amphibians
(((([5733,6370,6671,7338]-[988,1098,1208])*33)/([11,12,13]-[0])) = [11061, 13918, 15992, 19957] years

Birds
(((([8937,9930,10064,11070]-[3756,4173,4590])*33)/([13,14,15]-[7.2,8,8.8])) = [18391, 31664, 32401, 57467] years

Mammals
(((([4951,5501,6051]-[1366,1518,1670])*33)/([2.7,3,3.3]-[0])) = [28493, 37554, 52576, 70275] years

Reptiles
((([3297,3663,9547,10502]-[710,789,868])*33)/([3.6,4.4.4]-[2.7,3,3.3])) = [47151.17, 94842, 289014, 1077120] years

Bony Fishes
((([8254,9171,31193,34312]-[1897,2108,2319])*33)/([28,31,34]-[0])) = [5677, 7399, 31469, 38898] years

Hagfishes
(([68,76,84]*33)/[0]) = empty set/undefined

Lampreys
((([17,19,38,42]-[5.4,6,6.6])*33)/([0.9,1,1.1]-[0])) = [215, 286, 2112, 3020] years

Cartilaginous Fishes
(([984,1093,1202]*33)/[0]) = empty set/undefined

Vertebrates
((([32361,35957,64283,70711]-[9406,10451,11496])*33)/([59,65,72]-[10,11,12])) = [11106, 15587, 32897, 43044] years

<u>Years until total extinction for each taxon based on post-1500 extinction including impaired species.</u>

$(N_{\text{extant taxon species}} \times 513 \text{ years})/(N_{\text{recent taxon extinctions}} + N_{\text{impaired taxa}})$

Amphibians
(([5733,6370,6671,7338]*513)/([34,38,42]+[1738,1931,2124])) = [1357.815, 1659.629, 1738.052, 2124.376] years

Birds
(([8937,9930,10064,11070]*513)/([121,134,147]+[1061,1179,1297])) = [3175, 3880, 3932, 4804] years

Mammals
(([4951,5501,6051]*513)/([71,79,87]+[1026,1140,1254])) = [1894, 2315, 2830] years

Reptiles
(([3297,3663,9547,10502]*513)/([20,22,24]+[722,802,882])) = [1867, 2280, 5944, 7261] years

Bony Fishes
(([8254,9171,31193,34312]*513)/([59,66,73]+[1743,1937,2131])) = [1921, 2349, 7989, 9768] years

Hagfishes
(([68,76,84]*513)/([0]+[8.1,9,9.9])) = [3354, 4104, 4587, 5670] years

Lampreys
(([17,19,38,42]*513)/([0.9,1,1.1]+[2.7,3,3.3])) = [1982, 2437, 4874, 5985] years

Cartilaginous Fishes
(([984,1093,1202]*513)/([0]+[164,182,200])) = [2518, 3072, 3089, 3771] years

Vertebrates
(([32361,35957,64283,70711]*513)/([306,340,374]+[6504,7227,7950])) = [1994, 2438, 4358, 5327] years

<u>Years until total extinction for each taxon based on post-1500 extinction including impaired species but excluding island species.</u>

($N_{\text{extant taxon species}}$ × 513 years)/($N_{\text{recent taxon extinctions}}$ + $N_{\text{impaired taxa}}$)

Amphibians
((([5733,6370,6671,7338]-[988,1098,1208])*513)/([34,38,42]-[0] +[1738,1931,2124])) = [1071, 1373, 1452, 1839] years

Birds (the +10% estimate for island extinctions was reduced from 132 to 120 to avoid dividing by zero).
((([8937,9930,10064,11070]-[3756,4173,4590])*513)/([121,134,147]-[108,120,120]+[1061,1179,1297])) = [1669, 2476, 2533, 3533] years

Mammals
((([4951,5501,6051]-[1366,1518,1670])*513)/([71,79,87]-[32,36,40]+[1026,1140,1254])) = [1286, 1727, 2274] years

Reptiles (The +10% estimate for island extinctions was reduced from 20 to 19 to avoid dividing by zero).
((([3297,3663,9547,10502]-[710,789,868])*513)/([20,22,24]-[16,18,19]+[722,802,882])) = [1400, 1829, 5574, 6948] years

Bony Fishes
((([8254,9171,31193,34312]-[1897,2108,2319])*513)/([59,66,73]-[1.8,2,2.2]+[1743,1937,2131])) = [1383, 1811, 7457, 9239]years

Hagfishes
((([68,76,84])*513)/([0]+[8.1,9,9.9])) = [3354, 4104, 4587, 5670] years

Lampreys
((([17,19,38,42]-[5.4,6,6.6])*513)/([0.9,1,1.1]-[0]+[2.7,3,3.3])) = [1089, 1482, 4690, 6057] years

Cartilaginous Fishes
(([984,1093,1202]*513)/[0]+[164,182,200])) = [2524, 3081, 3760]

Vertebrates
((([32361,35957,64283,70711]-[9406,10451,11497])*513)/([306,340,374]-[158,176,194]+[6504,7227,7950])) = [1311, 1770, 3736, 4754] years

<u>Years until total extinction for each taxon based on post-1980 extinction rate including impaired species.</u>

$(N_{\text{extant taxon species}} \times 33 \text{ years})/(N_{\text{recent taxon extinctions}} + N_{\text{impaired taxa}})$

Amphibians
(([5733,6370,6671,7338]*33)/([11,12,13]+[1738,1931,2124])) = [89, 108, 113, 138] years

Birds
(([8937,9930,10064,11070]* 33)/([13,14,15]+[1061,1179,1297])) = [224, 275, 278, 340] years

Mammals
(([4951,5501,6051]*33)/([2.7,3,3.3]+[1026,1140,1254])) = [130, 159, 194]years

Reptiles
(([3297,3663,9547,10502]*33)/([3.6,4,4.4]+[722,802,882])) = [123, 150, 391, 478] years

Bony Fishes
(([8254,9171,31193,34312]*33)/([28,31,34]+[1743,1937,2131])) = [126, 154, 523, 639] years

Hagfishes
(([68,76,84]*33)/([0]+[8.1,9,9.9])) = [3354, 4104, 4587, 5670] years

Lampreys
(([17,19,38,42]*33)/([0.9,1,1.1]+[2.7,3,3.3])) = [128, 157, 314, 385] years

Cartilaginous Fishes
(([984,1093,1202]*33)/([0]+[164,182,200])) = [162, 198, 199, 243] years

Vertebrates
(([32361,35957,64283,70711]*33)/([59,65,72]+[6504,7227,7950])) = [133, 163, 291, 356] years

<u>Years until total extinction for each taxon based on post-1980 extinction rate including impaired species but excluding island species.</u>

$(N_{\text{extant taxon species}} \times 33 \text{ years})/(N_{\text{recent taxon extinctions}} + N_{\text{impaired taxa}})$

Amphibians
((([5733,6370,6671,7338]-[988,1098,1208])*33)/([11,12,13]-[0]+[1738,1931,2124]))
= [70, 90, 95, 120] years

Birds
(((([8937,9930,10064,11070]-[3756,4173,4590])*33)/([13,14,15]-[7.2,8,8.8]+[1061,1179,1297]))
= [110,160,164,227] years

Mammals
(((([4951,5501,6051]-[1366,1518,1670])*33)/([2.7,3,3.3]-[0]+[1026,1140,1254]))
= [86,115,150] years

Reptiles
(((([3297,3663,9547,10502]-[710,789,868])*33)/([3.6,4,4.4]-[2.7,3,3.3]+[722,802,882])) =
[90,118,360,447] years

Bony Fishes
(((([8254,9171,31193,34312]-[1897,2108,2319])*33)/([28,31,34]-[0]+[1743,1937,2131])) =
[90,118,487,604] years

Hagfishes
((([68,76,84]*33)/[0]+[8.1,9,9.9])) = [227,279,342] years

Lampreys
(((([17,19,38,42]-[5.4,6,6.6])*33)/([0.9,1,1.1]-[0]+[2.7,3,3.3])) = [70,95,302,390] years

Cartilaginous Fishes
((([984,1093,1202]*33)/([0]+[164,182,200])) = [162,198,199,243] years

Vertebrates
(((([32361,35957,64283,70711]-[9406,10451,11496])*33)/([59,65,72]-
[10,11,12]+[6504,7227,7950])) = [86,116,244,309] years

<u>Years until total extinction for each taxon based on post-1500 extinction rate including data deficient species as extinct.</u>

$(N_{\text{taxon species}} \times 513 \text{ years})/\ (N_{\text{recent taxon extinctions}} + N_{\text{data deficient}})$

Amphibians
((([5733,6370,6671,7338]*513)/([1614]+[34,38,42]) =
[1775.447, 1977.494, 2072.191, 2284.913] years

Birds
((([8937,9930,10064,11070]*513)/([62]+[121,134,147])) =
[21883.91, 25924.12, 26408.35, 31117.32] years

Mammals
((([4951,5501,6051]*513)/([799]+[71,79,87])) =
[2865.045, 3212.308, 3215.97, 3570.056] years

Reptiles
((([3297,3663,9547,10502]*513)/([811]+[20,22,24])) =
[2024.369, 2254.491, 5883.017, 6487.088] years

Bony Fishes
((([8254,9171,31193,34312]*513)/([2184]+[59,66,73])) =
[1875.659, 2090.523, 7113.585, 7849.301] years

Hagfishes
((([68,76,84]*513)/[30]) = [996.6857, 1113.942, 1559.52, 1723.68] years

Lampreys
((([17,19,38,42]*513)/([4])+[0.9,1,1.1]) =
[1938.9, 2167, 5570.715, 6157.1] years

Cartilaginous Fishes
((([984,1093,1202]*513)/[502]) = [1004.561, 1115.838, 1118.064, 1229.564] years

Vertebrates
((([32361,35957,64283,70711]*513)/([6006]+[306,340,374])) =
[2601.863, 2906.474, 5196.94, 5747.405]years

<u>Years until total extinction for each taxon based on post-1500 extinction rate excluding island species and including data deficient species as extinct.</u>

$(N_{\text{extant taxon species}} - N_{\text{island species}}) \times 513$ years)/ $(N_{\text{data deficient}} + N_{\text{recent taxon extinctions}} - N_{\text{island extinctions}})$

Amphibians
(((([5733,6370,6671,7338]-[988,1098,1208])*513)/([1614]+[34,38,42]-[0])) =
[1400.92, 1636.137, 1731.647, 1977.869] years

Birds
(the +10% estimate for island extinctions was reduced from 132 to 120 to avoid dividing by zero).
(((([8937,9930,10064,11070]-[3756,4173,4590])*513)/([62]+[121,134,147]-[108,120,120]))
[21970.55, 38605.76, 40027.59, 60033.32] years

Mammals
(((([4951,5501,6051]-[1366,1518,1670])*513)/([799]+[71,79,87]-[32,36,40]))
= [1969.751, 2425.256, 2428.14, 2897.415] years

Reptiles (The +10% estimate for island extinctions was reduced from 20 to 19 to avoid dividing by zero).
(((([3297,3663,9547,10502]-[710,789,868])*513)/([811]+[20,22,24]-[16,18,19])) =
[1520.533, 1807.923, 5516.089, 6190.137] years

Bony Fishes
((([8254,9171,31193,34312]-[1897,2108,2319])*513)/([2184]+[59,66,73]-[1.8,2,2.2]))
= [1349.76, 1611.438, 6638.757, 7422.62] years

Hagfishes
([68,76,84]*513)/([30]) =
[996.6857, 1113.942, 1559.52, 1723.68] years
Lampreys
((([17,19,38,42]-[5.4,6,6.6])*513)/([4]+[0.9,1,1.1]-[0]) =
[874.6229, 1111.5, 4104, 4814.308] years

Cartilaginous Fishes
([984,1093,1202]*513)/[502] = [1004.561, 1115.838, 1118.064, 1229.564] years

Vertebrates
((([32361,35957,64283,70711]-[9406,10451,11497])*513)/([6006]+[306,340,374]-
[158,176,194])) = [1720.085, 2120.505, 4476.184, 5140.902] years

<u>Years until total extinction for each taxon based on post-1980 extinction rate.with data deficient species included as extinct.</u>

($N_{\text{extant taxon species}}$ × 33 years)/ $N_{\text{recent taxon extinctions}}$n + $N_{\text{data deficient}}$

Amphibians
([5733,6370,6671,7338]*33)/([1614]+[11,12,13]) =
[116.2451, 129.2407, 135.431, 149.0638] years

Birds
([8937,9930,10064,11070]*33)/([62]+[13,14,15]) =
[3805.432, 4283.529, 4398.835, 4903.49] years

Mammals
([4951,5501,6051]*33)/([799]+[2.7,3,3.3]) =
[203.5164, 226.2093, 226.4916, 249.23] years

Reptiles
([3297,3663,9547,10502]*33)/([811]+[3.6,4,4.4]) =
[133.3509, 148.2268, 386.803, 425.7045] years

Bony Fishes
([8254,9171,31193,34312]*33)/([2184]+[28,31,34]) =
[122.7775, 136.6025, 464.8314, 512.0037] years

Hagfishes
(([68,76,84]*33)/[30]) = [64.11428, 71.65714, 100.32, 110.88] years

Lampreys
([17,19,38,42]*33)/([4]+[0.9,1,1.1]) =
[100.1785, 114, 278.6667, 315] years

Cartilaginous Fishes
([984,1093,1202]*33)/([502]) =
[64.62089, 71.7791, 71.92224, 79.09472]

Vertebrates
([32361,35957,64283,70711]*33)/([6006]+[59,65,72]) =
[175.6869, 195.4345, 349.4505, 384.7742] years

<u>Years until total extinction for each taxon based on post-1980 extinction rate excluding island species and including data deficient species as extinct.</u>

$(N_{\text{extant taxon species}} \times 33 \text{ years})/ (N_{\text{recent taxon extinctions}} + N_{\text{data deficient}})$

Amphibians
((([5733,6370,6671,7338]-[988,1098,1208])*33)/([1614]+[11,12,13]-[0])) =
[91.72297, 106.9305, 113.1748, 129.0333] years

Birds
((([8937,9930,10064,11070]-[3756,4173,4590])*33)/([62]+[13,14,15]-[7.2,8,8.8])) =
[2040.554, 2773.445, 2880.045, 3673.699] years

Mammals
((([4951,5501,6051]-[1366,1518,1670])*33)/([799]+[2.7,3,3.3]-[0])) =
[134.7852, 163.6849, 164.0937, 193.0873] years

Reptiles
(([3297,3663,9547,10502]-[710,789,868])*33)/([811]+[3.6,4,4.4]-[2.7,3,3.3]) =
[98.56984, 116.7286, 356.1479, 398.5398] years

Bony Fishes
((([8254,9171,31193,34312]-[1897,2108,2319])*33)/([2184]+[28,31,34]-[0])) =
[88.26273, 105.18, 433.5163, 483.806] years

Hagfishes
(([68,76,84]*33)/[30]) = [64.11428, 71.65714, 100.32, 110.88] years

Lampreys
(([17,19,38,42]-[5.4,6,6.6])*33)/([4]+[0.9,1,1.1]-[0]) =
[56.26229, 71.5, 264, 309.6924] years

Cartilaginous Fishes
((\[984,1093,1202]*33)/[502]) = [64.62089, 71.7791, 71.92224, 79.09472] years

Vertebrates
(([32361,35957,64283,70711]-[9406,10451,11496])*33)/([6006]+[59,65,72]-[10,11,12]) =
[113.4621, 138.8826, 293.1688, 334.2528] years

<u>Years until total extinction for each taxon based on post-1500 extinction including impaired species.</u>

$(N_{\text{extant taxon species}} \times 513 \text{ years})/(N_{\text{recent taxon extinctions}} + N_{\text{impaired taxa}} + N_{\text{data deficient}})$

Amphibians
(([5733,6370,6671,7338]*513)/([1614]+[34,38,42]+[1738,1931,2124])) =
[777.947, 911.9045, 955.2612, 1111.917] years

Birds
(([8937,9930,10064,11070]*513)/([62]+[121,134,147]+[1061,1179,1297])) =
[3043.266, 3703.446, 3756.153, 4566.876] years

Mammals
(([4951,5501,6051]*513)/([799]+[71,79,87]+[1026,1140,1254])) =
[1186.574, 1398.074, 1398.768, 1637.649] years

Reptiles
(([3297,3663,9547,10502]*513)/([811]+[20,22,24]+[722,802,882])) =
[984.7807, 1148.956, 2996.398, 3470.227] years

Bony Fishes
(([8254,9171,31193,34312]*513)/([2184]+[59,66,73]+[1743,1937,2131])) =
[964.8631, 1123.515, 3822.289, 4416.524] years

Hagfishes
(([68,76,84]*513)/([30]+[0]+[8.1,9,9.9])) =
[768.37, 876.1348, 1163.821, 1321.841] years

Lampreys
(([17,19,38,42]*513)/([4]+[0.9,1,1.1]+[2.7,3,3.3])) =
[979.8876, 1146.705, 2599.2, 3034.648] years

Cartilaginous Fishes
(([984,1093,1202]*513)/([502]+[0]+[164,182,200])) =
[718.054, 818.5532, 820.9503, 927.2572] years

Vertebrates
((([32361,35957,64283,70711]*513)/([6006]+[306,340,374]+[6504,7227,7950])) =
[1158.451, 1358.967, 2429.706, 2830.537] years

<u>Years until total extinction for each taxon based on post-1500 extinction including impaired species but excluding island species.</u>

$(N_{\text{extant taxon species}} \times 513 \text{ years})/(N_{\text{recent taxon extinctions}} + N_{\text{impaired taxa}} + N_{\text{data deficient}})$

Amphibians
(((([5733,6370,6671,7338]-[988,1098,1208])*513)/([1614]+[34,38,42]-[0] +[1738,1931,2124]))
= [613.9447, 754.6138, 798.1433, 962.3486] years

Birds (the +10% estimate for island extinctions was reduced from 132 to 120 to avoid dividing by zero).
(((([8937,9930,10064,11070]-[3756,4173,4590])*513)/([62]+[121,134,147]-[108,120,120]+[1061,1179,1297])) = [1594.573, 2352.322, 2408.995, 3339.637] years

Mammals
(((([4951,5501,6051]-[1366,1518,1670])*513)/([799]+[71,79,87]-[32,36,40]+[1026,1140,1254]))
= [798.2703, 1030.657, 1031.178, 1295.287] years

Reptiles (The +10% estimate for island extinctions was reduced from 20 to 19 to avoid dividing by zero).
(((([3297,3663,9547,10502]-[710,789,868])*513)/([811]+[20,22,24]-[16,18,19]+[722,802,882]))
= [732.3402, 911.5066, 2779.372, 3275.707] years

Bony Fishes
(((([8254,9171,31193,34312]-[1897,2108,2319])*513)/([2184]+[59,66,73]-[1.8,2,2.2]+[1743,1937,2131])) = [694.065, 865.6836, 3565.685, 4174.653] years

Hagfishes
(((([68,76,84])*513)/([30]+[0]+[8.1,9,9.9])) = [768.37, 876.1348, 1163.821, 1321.841] years

Lampreys
(((([17,19,38,42]-[5.4,6,6.6])*513)/([4]+[0.9,1,1.1]-[0]+[2.7,3,3.3])) =
[567.5744, 741, 2345.143, 2844.819] years

Cartilaginous Fishes
([984,1093,1202]*513)/([502]+[0]+[164,182,200]) =
[718.054, 818.5532, 820.9503, 927.2572] years

Vertebrates
(((([32361,35957,64283,70711]-[9406,10451,11497])*513)/([6006]+[306,340,374]-[158,176,194]+[6504,7227,7950])) = [755.2112, 976.6432, 2061.421, 2491.738] years

Years until total extinction for each taxon based on post-1980 extinction rate including impaired species and data efficient species as extinct.

$(N_{\text{extant taxon species}} \times 33 \text{ years})/(N_{\text{recent taxon extinctions}} + N_{\text{impaired taxa}} + N_{\text{data deficient}})$

Amphibians
(([5733,6370,6671,7338]*33)/([1614]+[11,12,13]+[1738,1931,2124])) =
[50.43022, 59.08924, 61.89878, 72.01606] years

Birds
(([8937,9930,10064,11070]* 33)/([62]+[13,14,15]+[1061,1179,1297])) =
[214.566, 261.0035, 264.7366, 321.7174] years

Mammals
(([4951,5501,6051]*33)/([799]+[2.7,3,3.3]+[1026,1140,1254])) =
[79.43553, 93.45328, 93.50142, 109.2837] years

Reptiles
(([3297,3663,9547,10502]*33)/([811]+[3.6,4,4.4]+[722,802,882])) =
[64.07974, 74.73199, 194.897, 225.6143] years

Bony Fishes
(([8254,9171,31193,34312]*33)/([2184]+[28,31,34]+[1743,1937,2131])) =
[62.62374, 72.88211, 247.9512, 286.3311] years

Hagfishes
(([68,76,84]*33)/([30]+[0]+[8.1,9,9.9])) =
[49.42731, 56.35955, 74.86568, 85.03068] years

Lampreys
(([17,19,38,42]*33)/([4]+[0.9,1,1.1]+[2.7,3,3.3])) =
[63.0337, 73.7647, 167.2, 195.2113] years

Cartilaginous Fishes
(([984,1093,1202]*33)/([502]+[0]+[164,182,200])) =
[46.19061, 52.65547, 52.80967, 59.64813] years

Vertebrates
(([32361,35957,64283,70711]*33)/([6006]+[59,65,72]+[6504,7227,7950])) =
[76.12453, 89.22667, 159.5292, 185.6597] years

Years until total extinction for each taxon based on post-1980 extinction rate including impaired species but excluding island species.

$(N_{\text{extant taxon species}} \times 33 \text{ years})/(N_{\text{recent taxon extinctions}} + N_{\text{impaired taxa}} + N_{\text{data deficient}})$

Amphibians
(((([5733,6370,6671,7338]-[988,1098,1208])*33)/([1614]+[11,12,13]-[0]+[1738,1931,2124])) =
[39.79877, 48.89713, 51.71795, 62.32898] years

Birds
(((([8937,9930,10064,11070]-[3756,4173,4590])*33)/([62]-[13,14,15]-
[7.2,8,8.8]+[1061,1179,1297])) = [107.1089, 155.7859, 159.5429, 219.6797] years

Mammals
(((([4951,5501,6051]-[1366,1518,1670])*33)/([799]+[2.7,3,3.3]-[0]+[1026,1140,1254])) =
[52.62868, 67.64745, 67.71716, 84.63623] years

Reptiles
(((([3297,3663,9547,10502]-[710,789,868])*33)/([811]+[3.6,4,4.4]-[2.7,3,3.3]+[722,802,882])) =
[47.28468, 58.74388, 179.1225, 210.8142] years

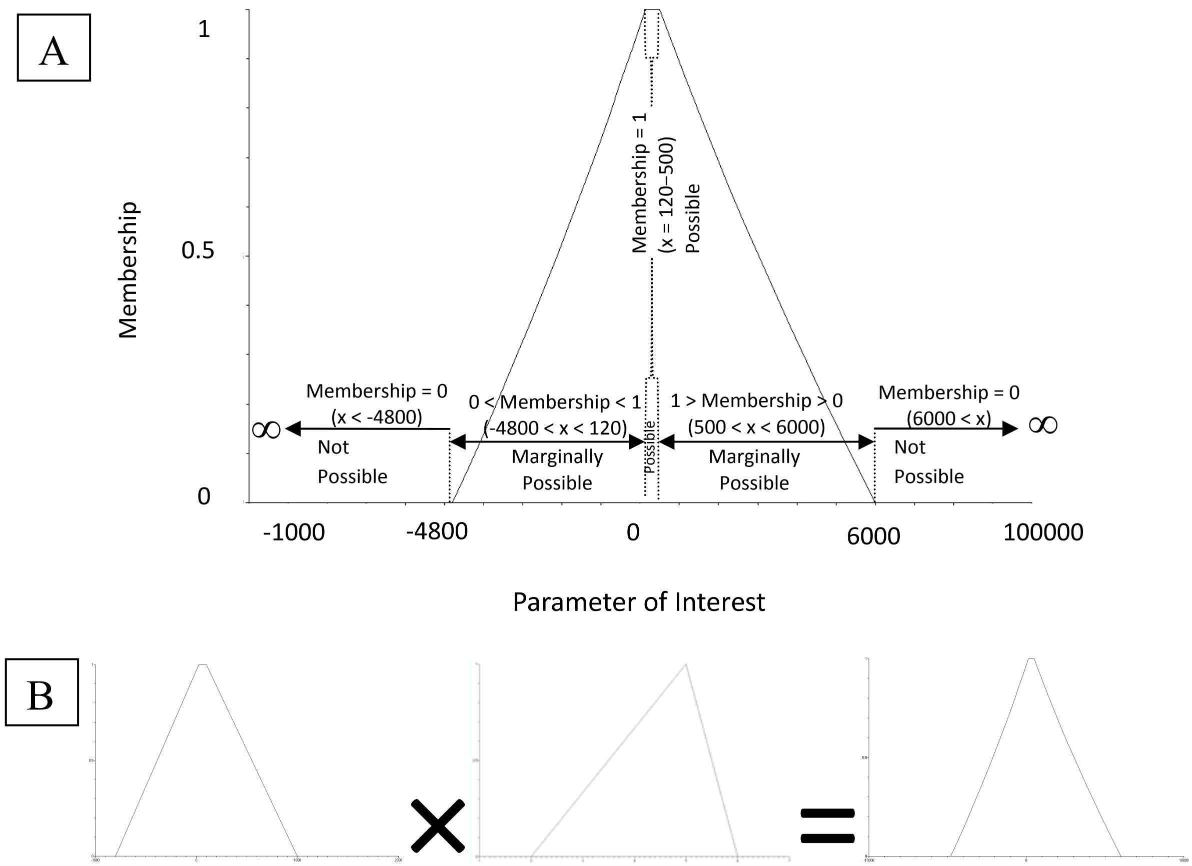
Bony Fishes
(((([8254,9171,31193,34312]-[1897,2108,2319])*33)/([2184]+[28,31,34]-[0]+[1743,1937,2131]))
= [45.02413, 56.12304, 231.2226, 270.535] years

Hagfishes
([68,76,84]*33)/([30]+[0]+[8.1,9,9.9]) =
[49.42731, 56.35955, 74.86568, 85.03068] years

Lampreys
(((([17,19,38,42]-[5.4,6,6.6])*33)/([4]+[0.9,1,1.1]-[0]+[2.7,3,3.3])) =
[36.51063, 47.66666, 150.8572, 183] years

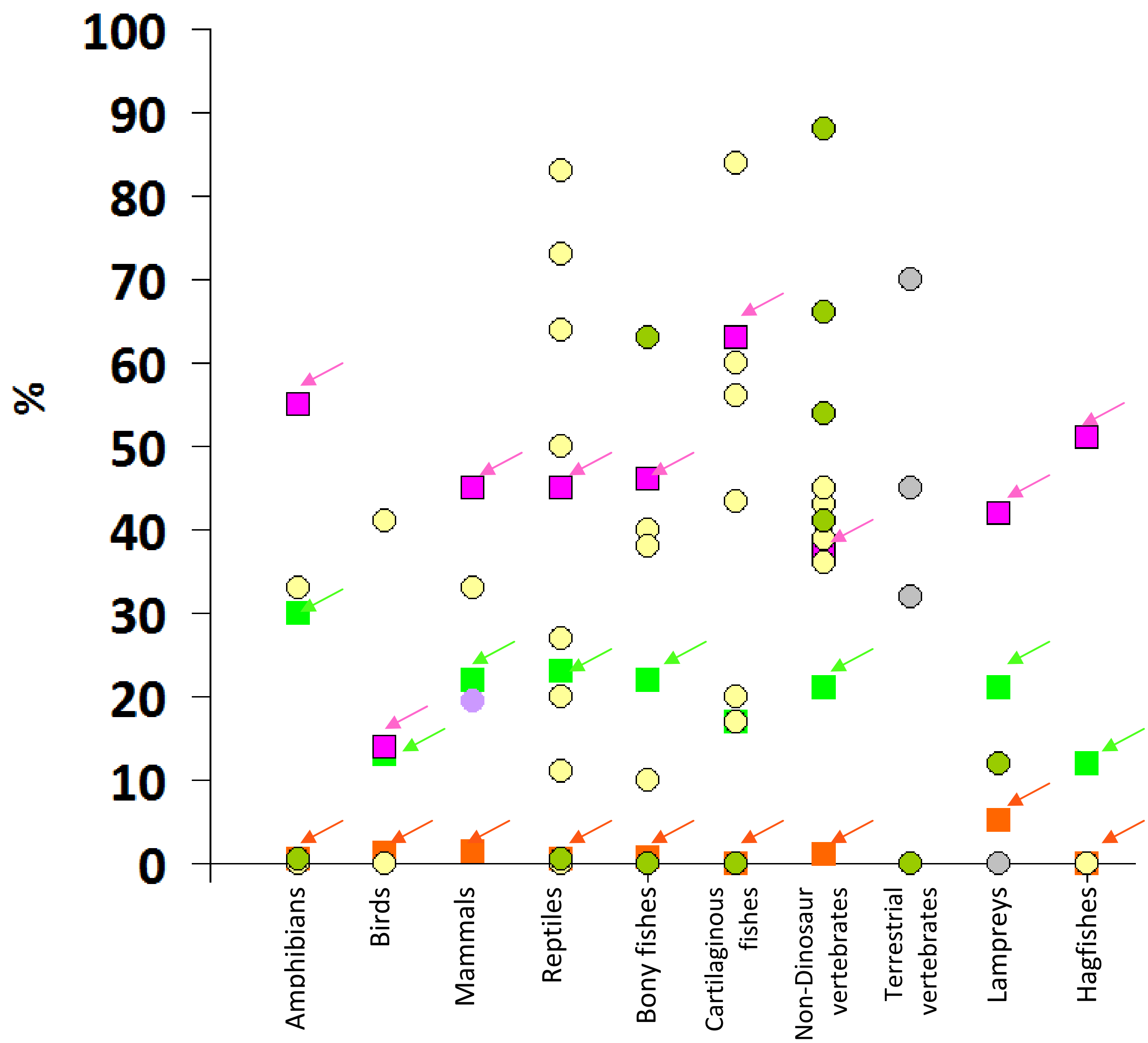
Cartilaginous Fishes
((([984,1093,1202]*33)/([502]+[0]+[164,182,200])) =
[46.19061, 52.65547, 52.80967, 59.64813] years

Vertebrates
(((([32361,35957,64283,70711]-[9406,10451,11496])*33)/([6006]+[59,65,72]-
[10,11,12]+[6504,7227,7950])) = [49.11688, 63.34509, 133.7039, 161.117] years

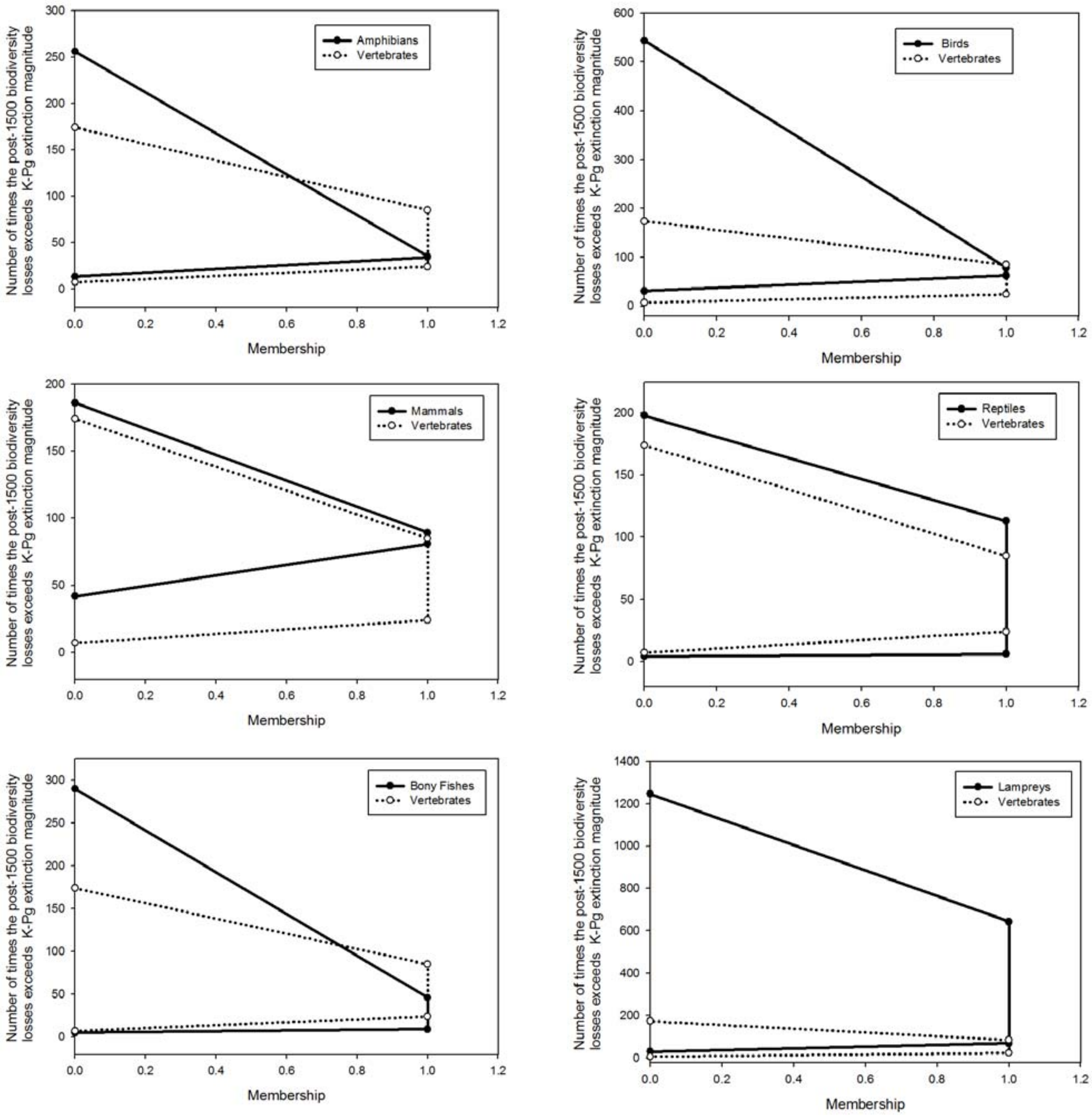


[-800, 24, 100, 1000] × [2, 5, 6] = [-4800, 120, 500, 6000]

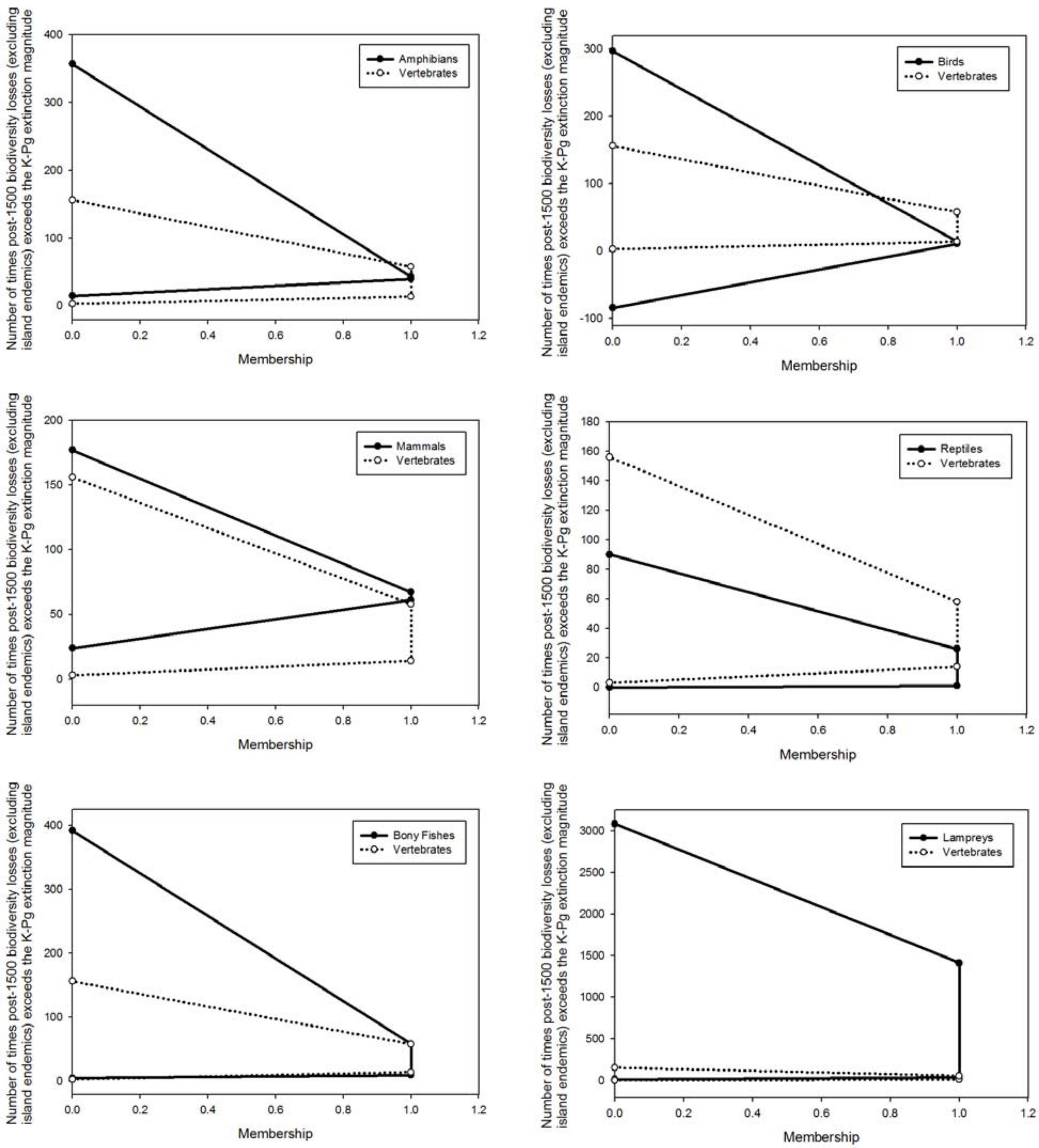
Supplemental Figure 1. Explanation of Fuzzy Arithmetic. A) Anatomy of a fuzzy set; B) Resulting shape of a fuzzy set after multiplication of a fuzzy set approximated by a trapazoid and another approximated by a triangle. Notice the resulting shape has legs with a concave curvature, causing membership to weaken at a delining rate as X diverges from Y = 1.



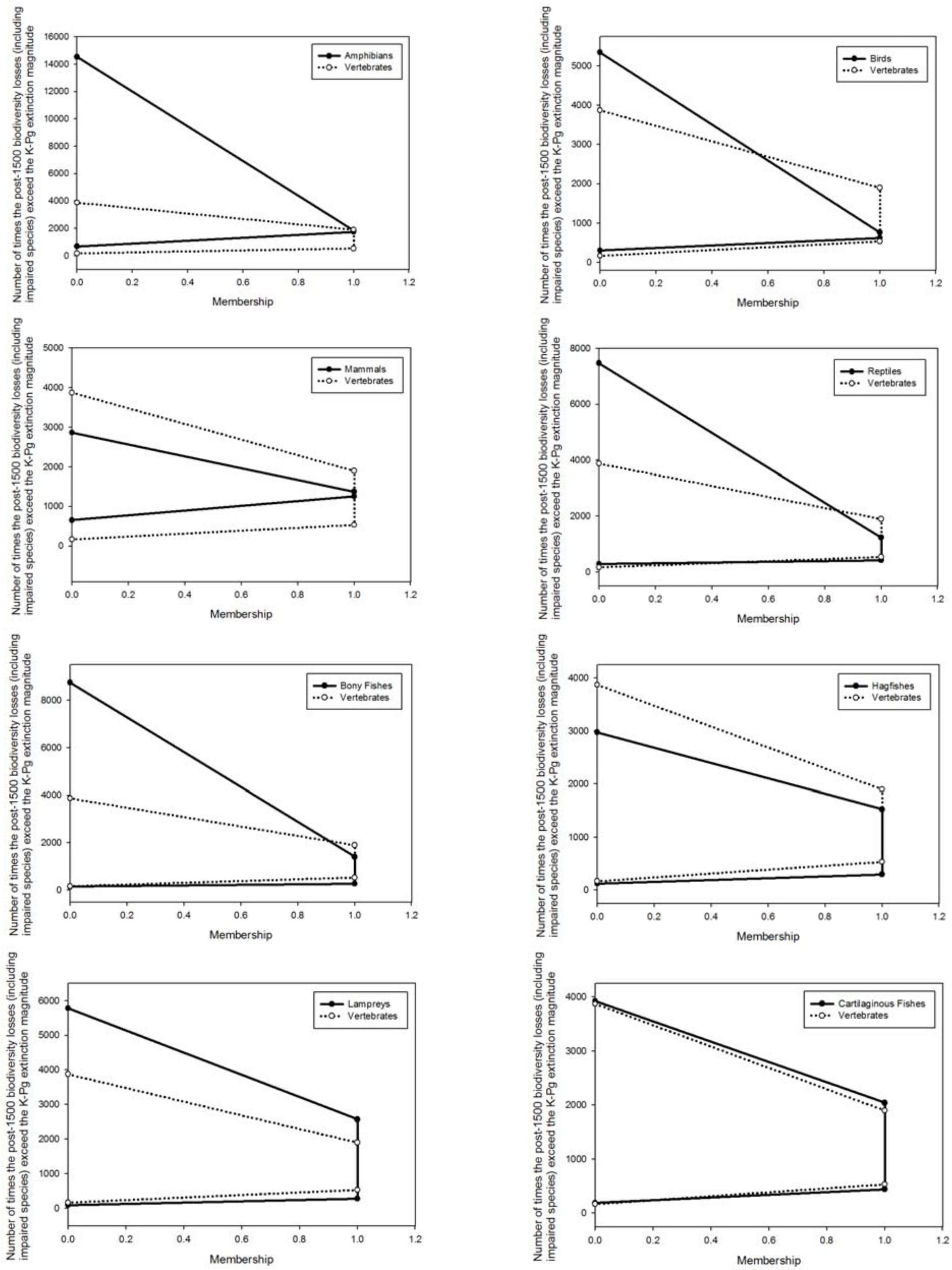
Supplemental Figure 2. Estimates the percent of contemporary species that are extinct and in danger of extinction, and estimates of percent extinction for the Cretaceous-Paleogene (*K-Pg*), Pleistocene, Permian, and Triassic-Jurassic extinctions. (IUCN/SSC Red List 2012; Archibald and Bryant 1990; Benton 1998; Benton 2005; Bryant 1989; Capetta 1987; Chiappe 1995; Clark et al. 2005; Clemmens 1986; Cooper and Penny 1997; Fitch and Ayala 1995; Fountaine et al. 2005; Hou et al. 1996; Kriwet and Benton 2004; Longrich et al. 2011; Longrich et al. 2012; MacLeod et l. 1997; Patterson 1993; Pimm 2002; Robertson et al. 2004; Sahney and Benton 2008; Foote 1997). ■ % of species gone extinct since 1500 AD, ■ % of species gone extinct since 1500 AD + impaired species, ■ % of species gone extinct since 1500 + impaired and data deficient species, ○ estimated % of species gone extinct during the Cretaceous-Paleogene extinction, ○ estimated % of species gone extinct during the Pleistocene megafauna extinction, ○ estimated % of species gone extinct during the Permian extinction, ○ estimated % of species gone extinct during the Triassic-Jurassic extinction.



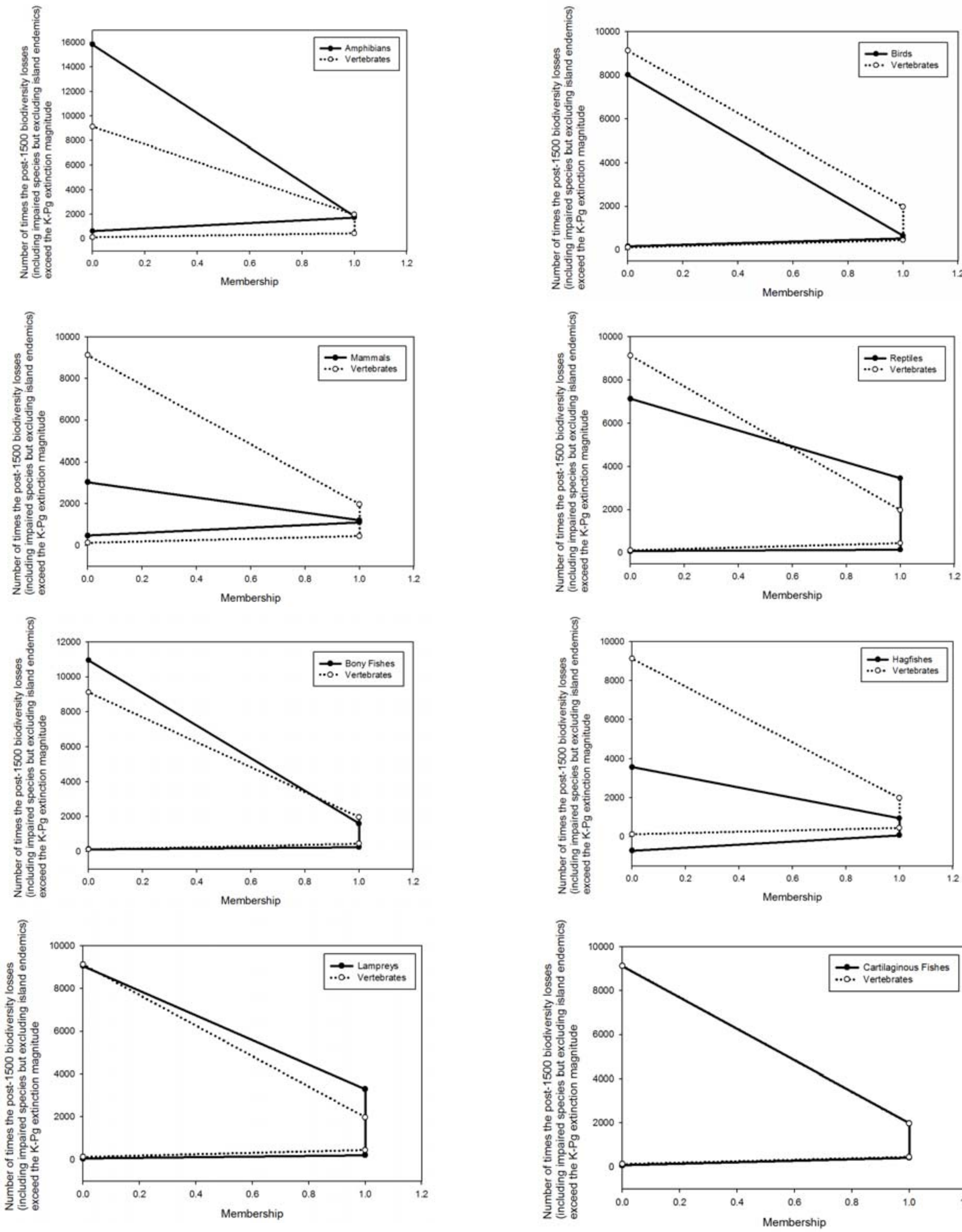
Supplemental Figure 3. Comparison of biodiversity losses since 1500 AD to the the magnitude of extinction for each taxon during the Cretaceous-Paleogene (*K-Pg*) Mass Extinction. The vertebrate extinction rate at *K-Pg* is used for lampreys.



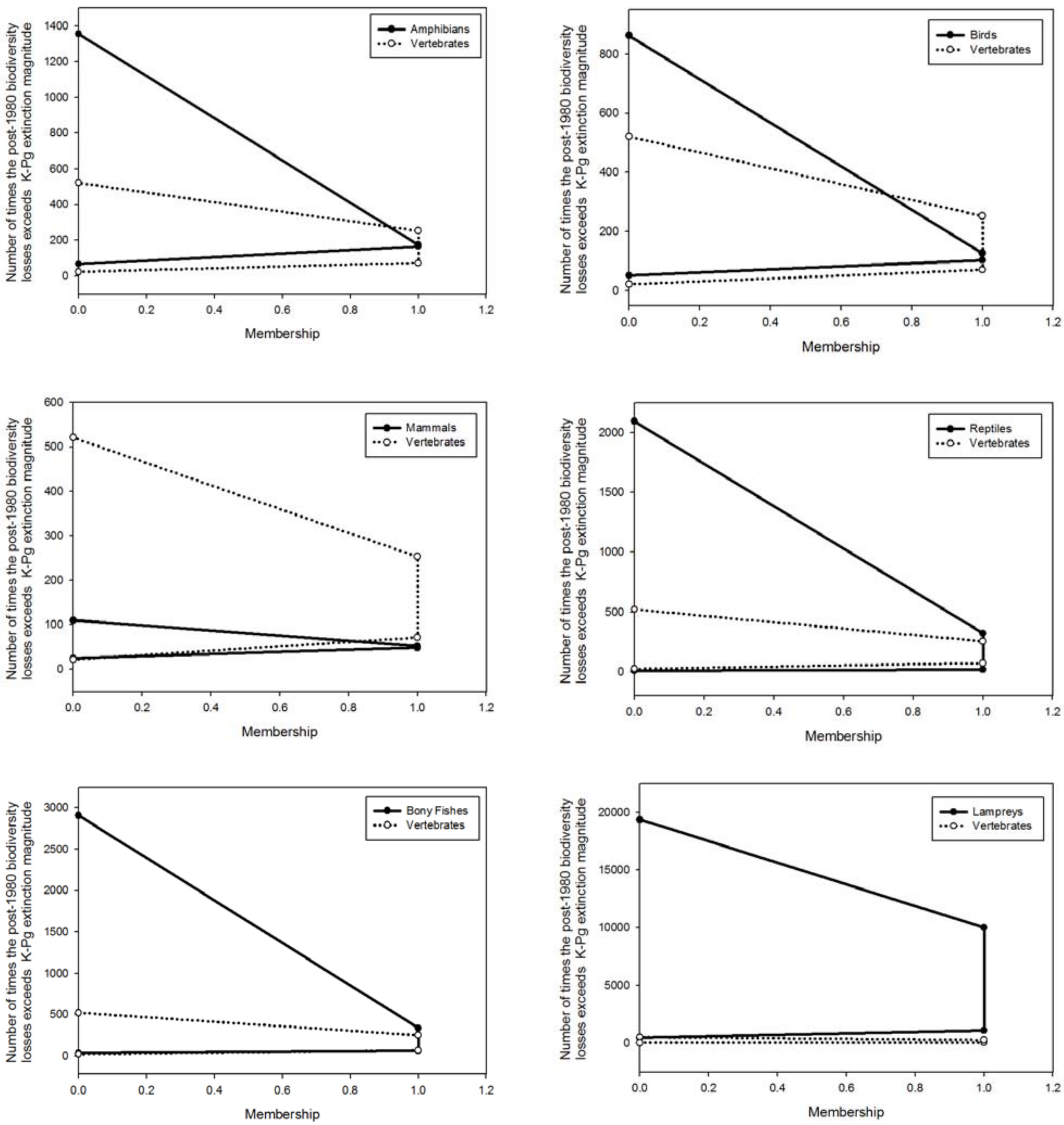
Supplemental Figure 4. Comparison of biodiversity losses since 1500 AD to the magnitude of extinction for each taxon during the Cretaceous-Paleogene (*K-Pg*) Mass Extinction. Island endemics are excluded. The vertebrate extinction rate at *K-Pg* is used for Lampreys.



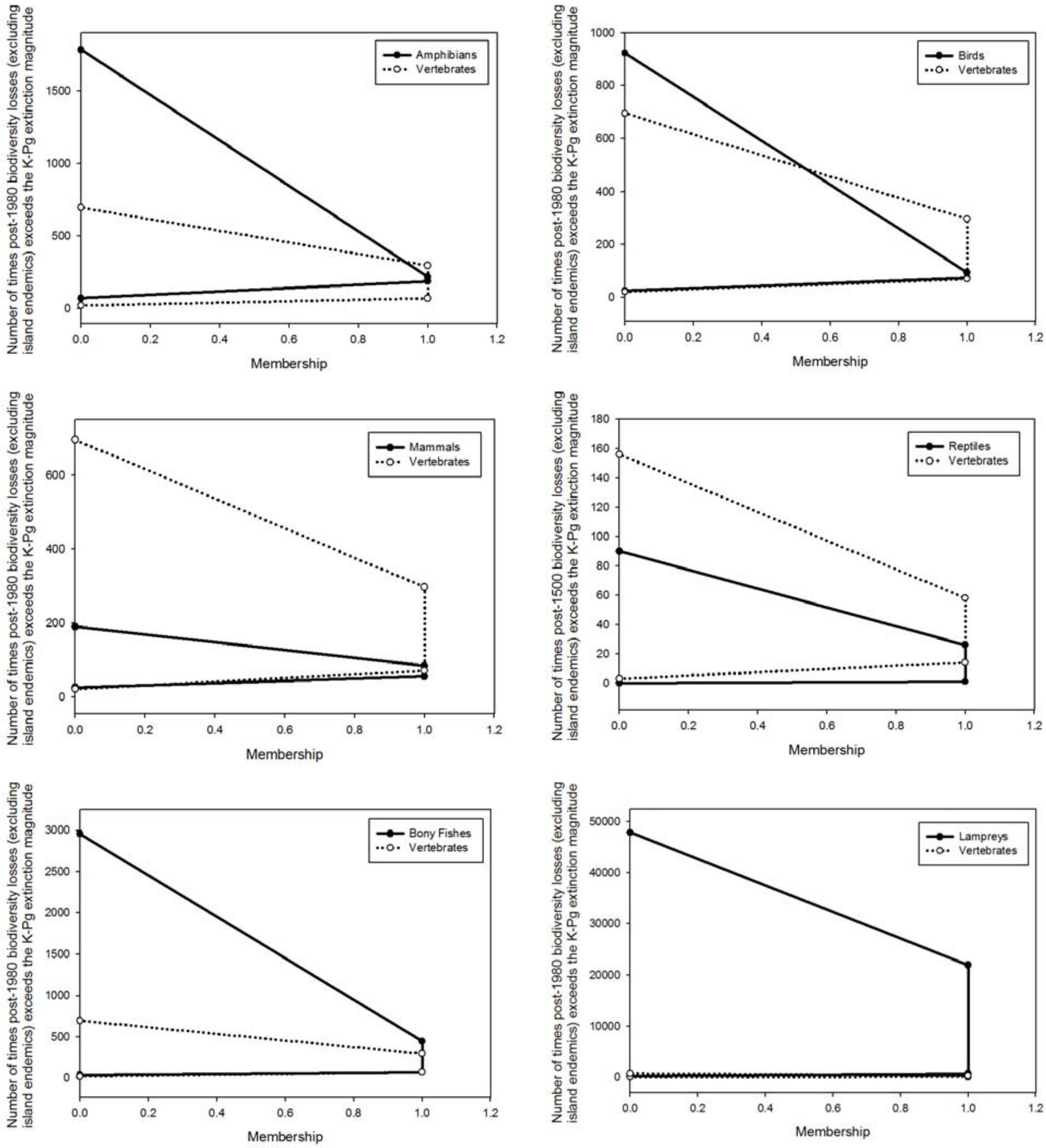
Supplemental Figure 5. Comparison of biodiversity losses since 1500 AD to extinction during the Cretaceous-Paleogene (*K-Pg*) Mass Extinction. Species with IUCN designations from Vulnerable (VU) to Extinct (EX) are included. Many of these species would go undetected in a fossil record, thus they are already extinct by geological standards. The vertebrate extinction rate at *K-Pg* is used for lampreys and hagfishes. Zero = extinction at *K-Pg*,



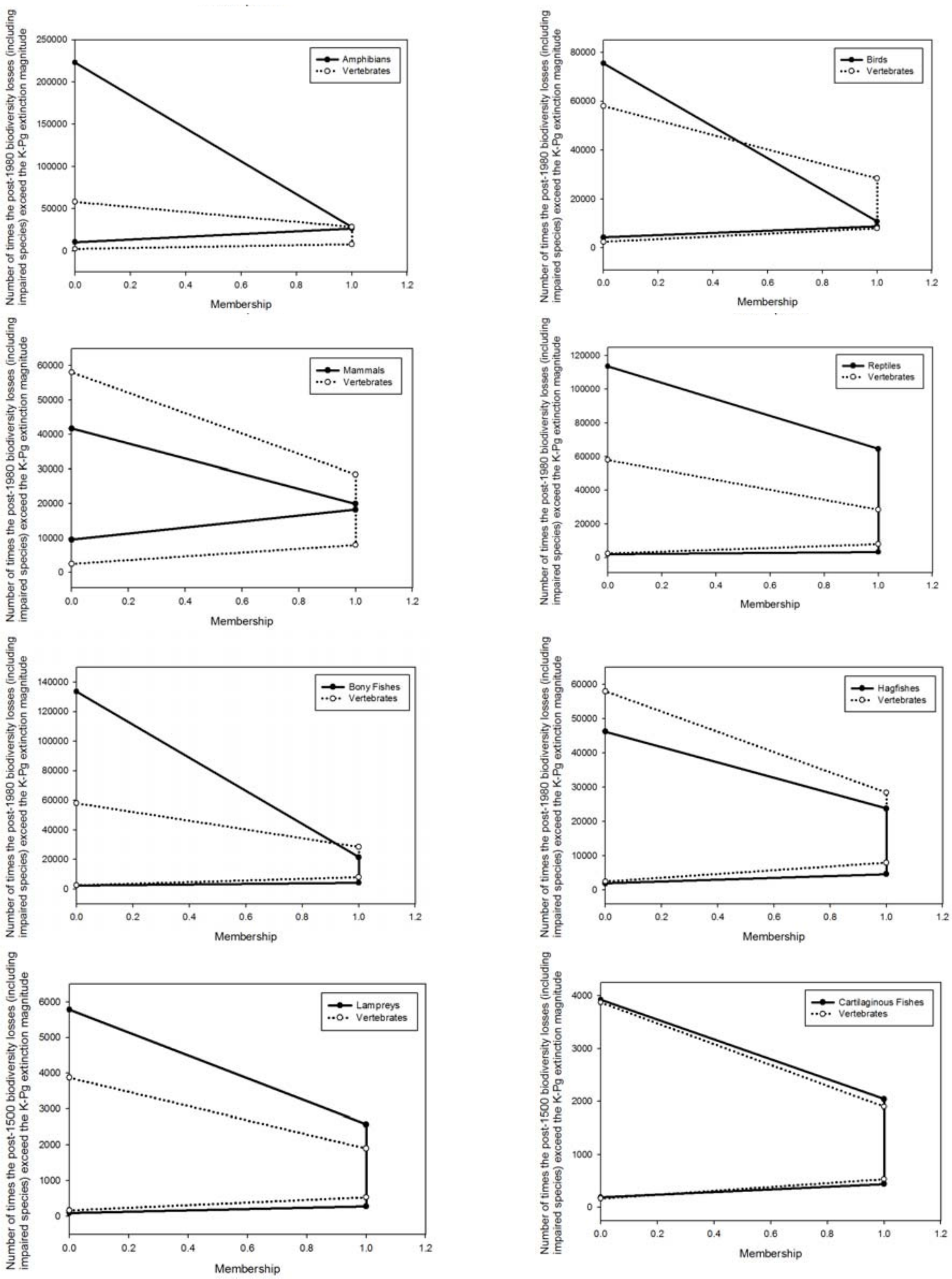
Supplemental Figure 6. Comparison of biodiversity losses since 1500 AD to the magnitude of extinction for each taxon during the Cretaceous-Paleogene (*K-Pg*) Mass Extinction. Those species with IUCN designations from Vulnerable (VU) to Extinct (EX) are included with extinctions. Many of these species would go undetected in a fossil record, thus they are already extinct by geological standards. Island endemics are excluded. The vertebrate extinction rate at *K-Pg* is used for lampreys and hagfishes. Zero = extinction at K-Pg, -values = lower extinction than *K-Pg*.



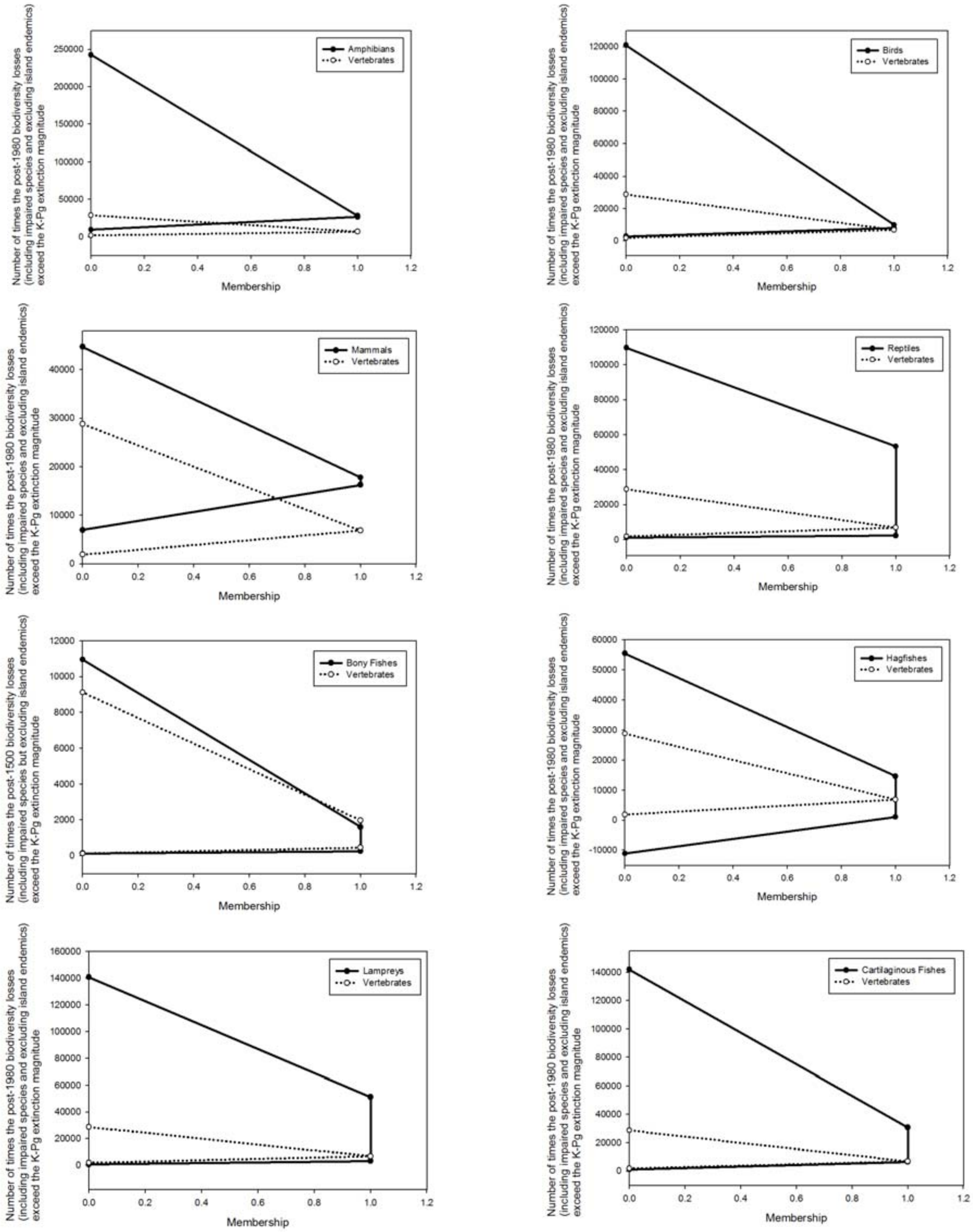
Supplemental Figure 7. Comparison of biodiversity losses since 1980 AD to the magnitude of extinction for each taxon during the Cretaceous-Paleogene (*K-Pg*) Mass Extinction. The vertebrate extinction rate at *K-Pg* is used for lampreys.



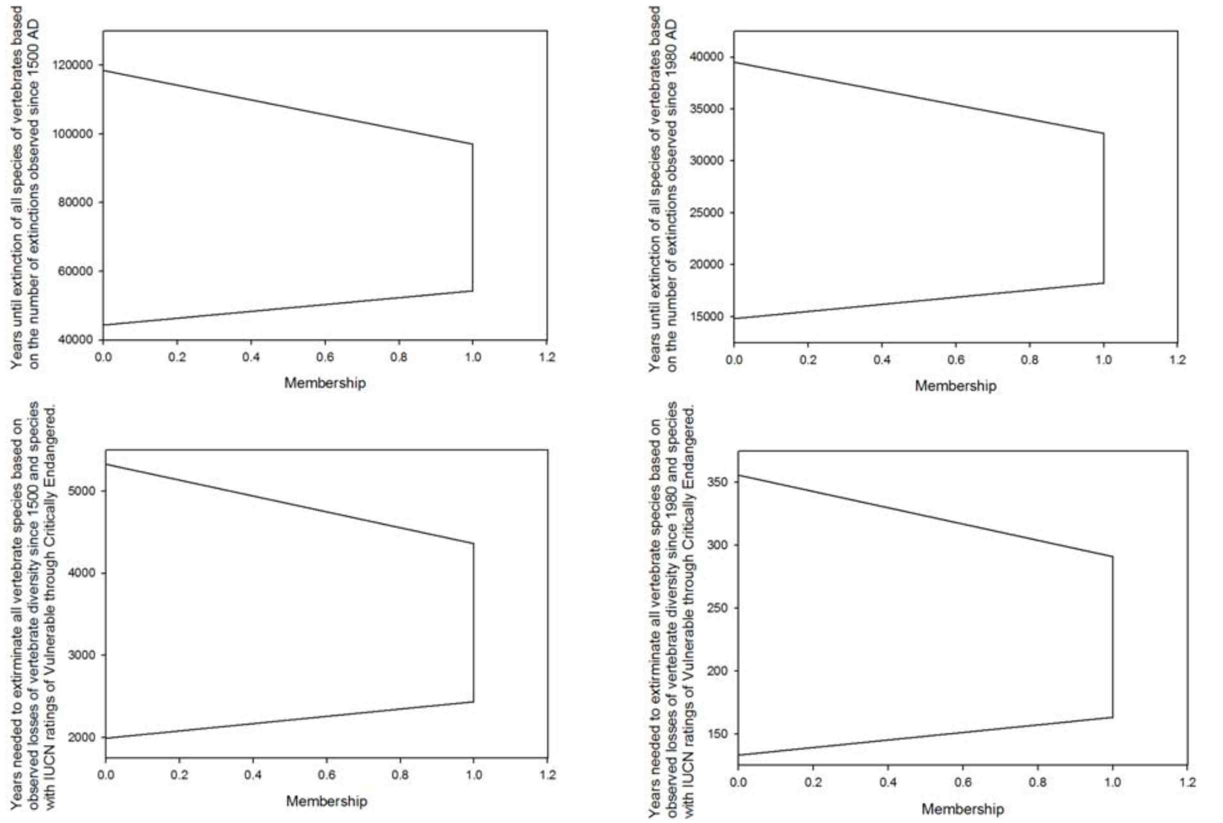
Supplemental Figure 8. Comparison of biodiversity losses since 1980 AD to the magnitude of extinction for each taxon during the Cretaceous-Paleogene (*K-Pg*) Mass Extinction. The vertebrate extinction rate at *K-Pg* is used for lampreys.



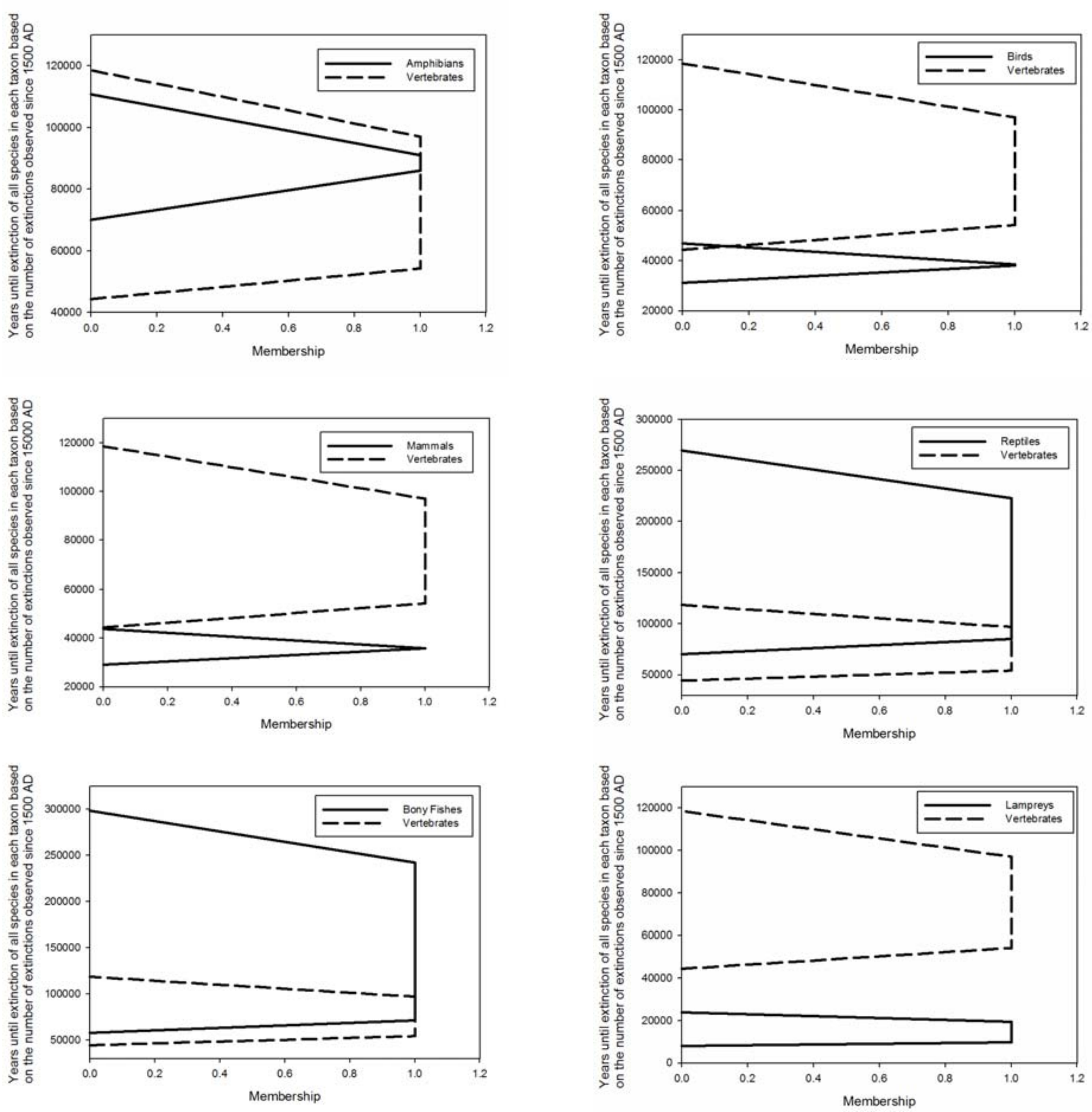
Supplemental Figure 9. Comparison of biodiversity losses since 1980 AD to the magnitude of extinction for each taxon during the Cretaceous-Paleogene (*K-Pg*) Mass Extinction. Those species with IUCN designations from Vulnerable (VU) to Extinct (EX) are included with extinctions. Many of these species would go undetected in a fossil record, thus they are already extinct by geological standards. The vertebrate extinction rate at *K-Pg* is used for lampreys and hagfishes. Zero = extinction at *K-Pg*.



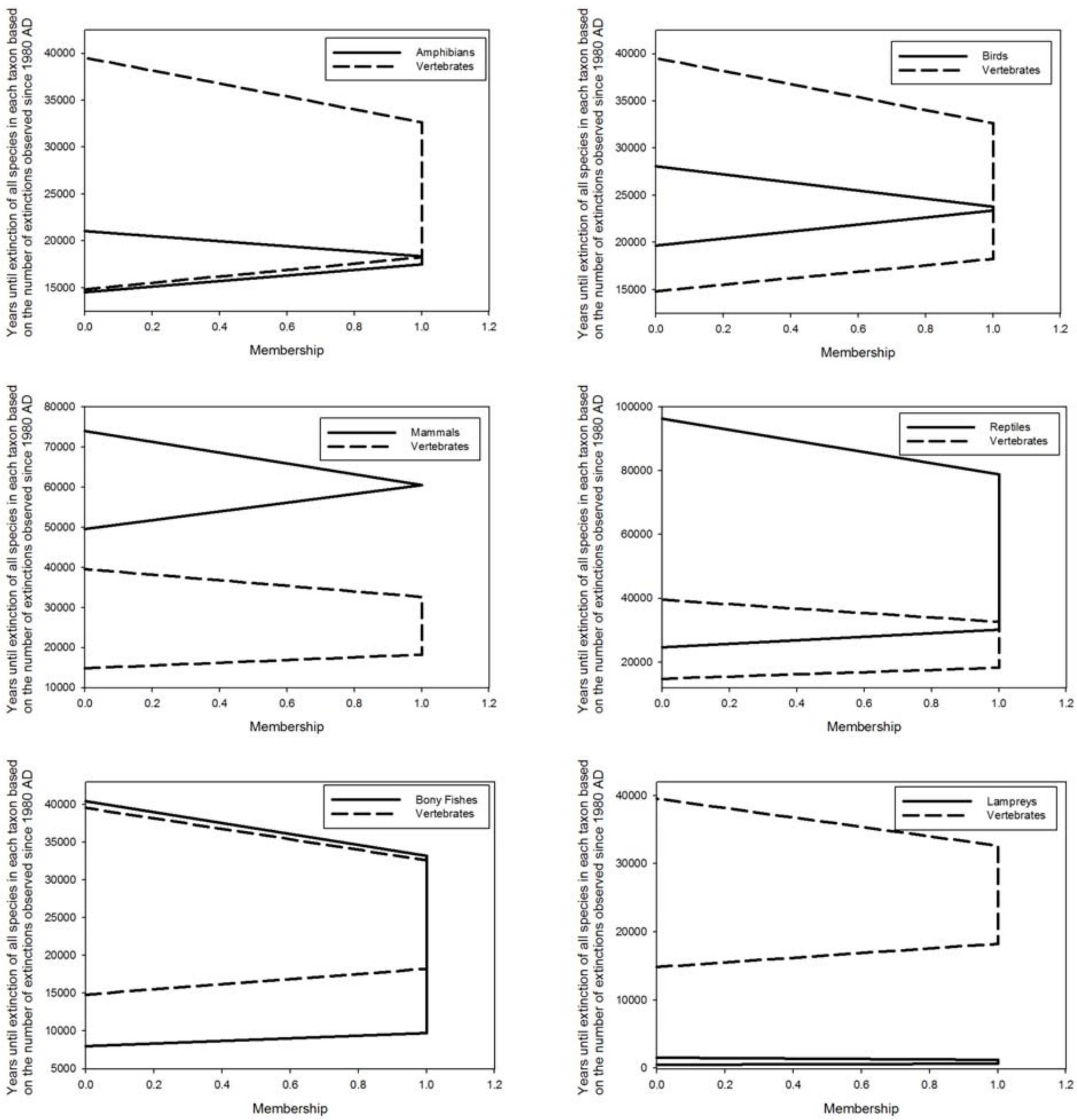
Supplemental Figure 10. Comparison of biodiversity losses since 1980 AD to the magnitude of extinction for each taxon during the Cretaceous-Paleogene (*K-Pg*) Mass Extinction. Those species with IUCN designations from Vulnerable (VU) to Extinct (EX) are included with extinctions. Many of these species would go undetected in a fossil record, thus they are already extinct by geological standards. Island endemics are excluded. The vertebrate extinction rate at *K-Pg* is used for lampreys and hagfishes. Zero = extinction at *K-Pg*, negative values = extinction lower than at *K-Pg*.



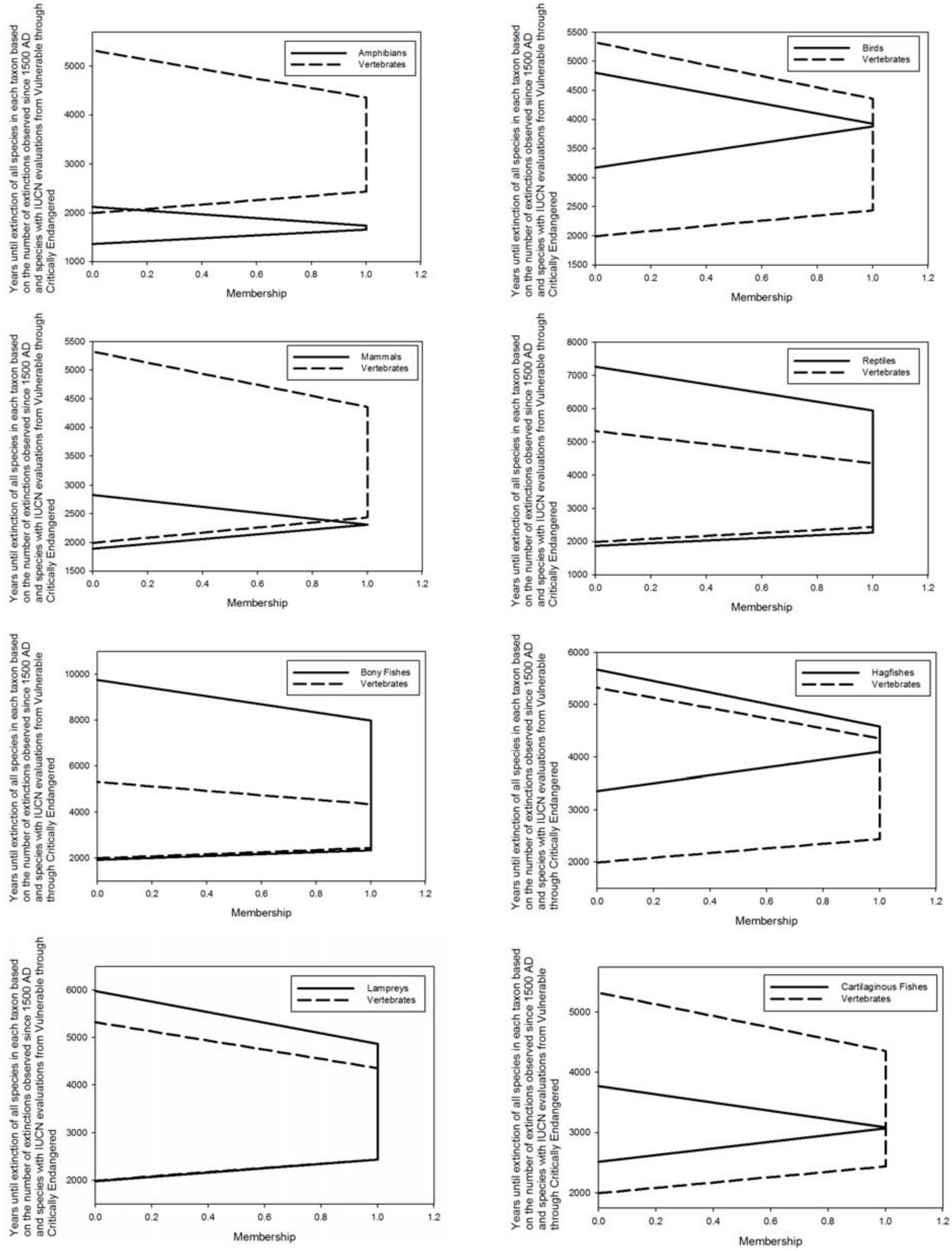
Supplemental Figure 11. Time necessary to drive the class Vertebrata extinct based on inclusion or exclusion of species having IUCN ratings of Vulnerable to Critically Endangered, and using extinctions observed since 1500 and since 1980.



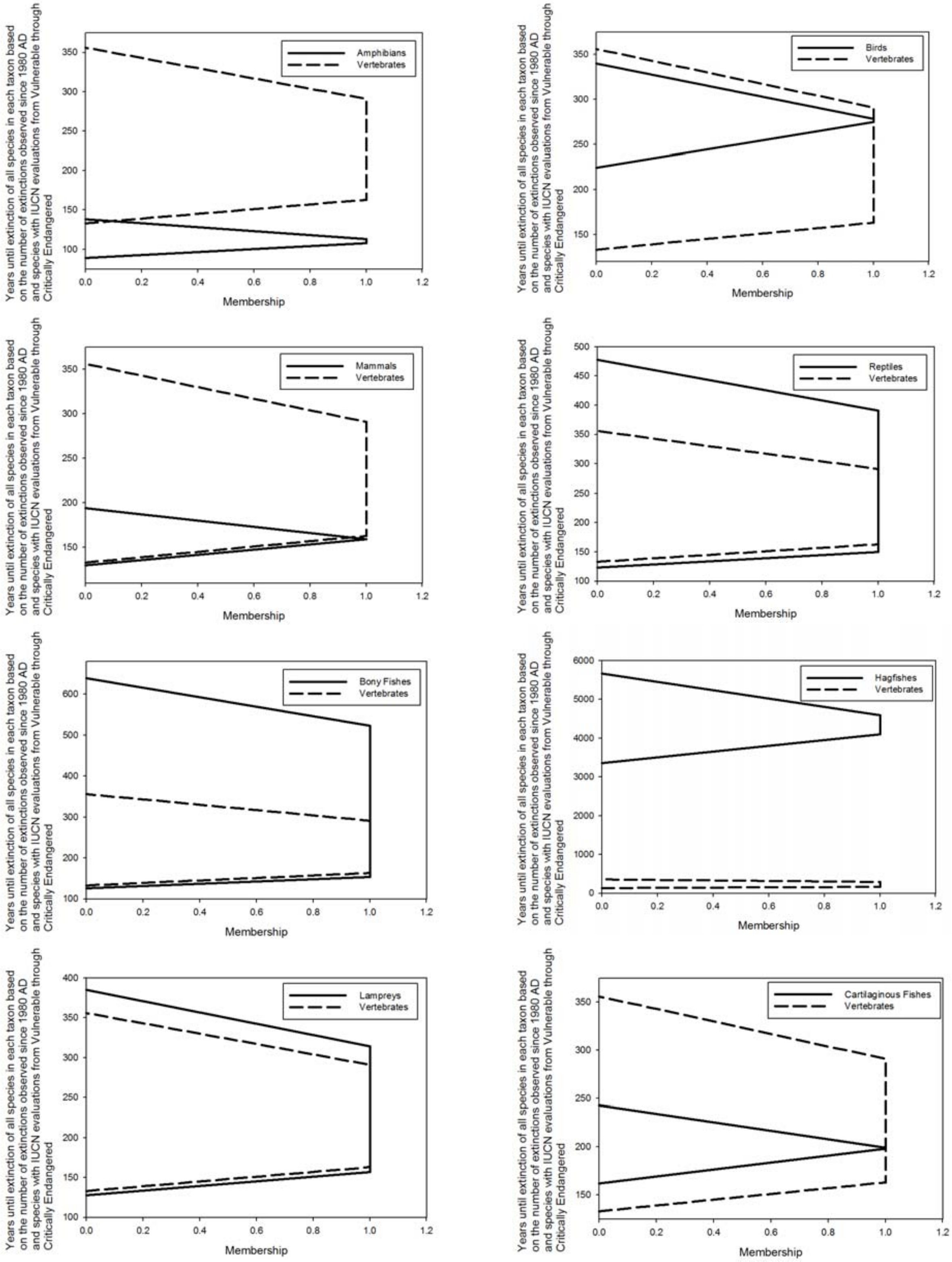
Supplemental Figure 12. Time required for extinction of all species in each group of vertebrates based on the magnitude of losses since 1500.



Supplemental Figure 13. Time required for extinction of all species in each group of vertebrates based on the magnitude of losses since 1980.



Supplemental Figure 14. Time required for extinction of all species in each group of vertebrates based on the magnitude of losses since 1500 with species ranked as Vulnerable through Critically endangered.



Supplemental Figure 15. Time required for extinction of all species in each group of vertebrates based on the magnitude of losses since 1980 with species ranked as Vulnerable through Critically endangered.