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Amphibian Decline or Extinction? Current Declines Dwarf Background Extinction Rate

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Abstract.—**Amphibian declines and extinctions are critical concerns of biologists around the world. The estimated current rate of amphibian extinction is known, but how it compares to the background amphibian extinction rate from the fossil record has not been well studied. I compared current amphibian extinction rates with their reported background extinction rates using standard and fuzzy arithmetic. These calculations suggest that the current extinction rate of amphibians could be 211 times the background amphibian extinction rate. If current estimates of amphibian species in imminent danger of extinction are included in these calculations, then the current amphibian extinction rate may range from 25,039–45,474 times the background extinction rate for amphibians. It is difficult to explain this unprecedented and accelerating rate of extinction as a natural phenomenon.**

''*As you walk from the terminal toward your airline, you notice a man on a ladder busily prying rivets out of its wing. Somewhat concerned, you saunter over to the rivet popper and ask just what the hell he's doing*.'' (Ehrlich and Ehrlich, 1981)

Amphibian extinctions are progressing at a remarkable rate (Blaustein et al., 1994; Houlahan et al., 2000). Some estimate that almost a third of amphibians are threatened with extinction (Stuart et al., 2004) although precise estimates are subject to argument (Pimenta et al., 2005; Stuart et al., 2005). The potential causes are numerous and include habitat degradation and loss (Brooks et al., 2002), introduced species (Adams, 1999), pollution (Dunson et al., 1992), contaminants (Reeder et al., 1998; Relyea, 2005), pathogens (Berger et al., 1998; Daszak et al., 2003), climate change (Pounds and Crump, 1994; Pounds et al., 1999), or interactions among several factors (Pounds et al., 2006; Trauth et al., 2006). Many of these implicated stressors trace directly or indirectly back to humans (Mendelson et al., 2006; Pounds et al., 2006; Trauth et al., 2006). Among the 1.4 million recorded (10 million estimated) extant species of organisms on the planet, amphibians comprise 5,918 of these (Aloy, 2002; Regan et al., 2001; IUCN et al., 2006). Although it is thought that 35 species of amphibians have gone extinct since 1500, this number may be closer to 130 (IUCN et al., 2006) with 9–122 species disappearing since 1980 (Mendelson et al., 2006). Another 1,896 species may be in imminent danger of extinction (IUCN et al., 2006). All of these estimates have a ± 10% error rate (IUCN et al., 2006) and represent the highest percent extinction rates for any vertebrate group (Regan et al., 2001).

Paleodiversity can be directly inferred from the fossil record with few assumptions needed (Smith, 2001). As much as 60–80% of all species are believed to have gone extinct during the Cretaceous-Tertiary (K-T) extinction (Raup, 1988), although some contend that this event was neither sudden nor catastrophic since it probably spanned 2.5–2.75 million years (Briggs, 1991). Despite this, most mass extinctions span about 260 million years (Thackeray, 1990). The terminal Cretaceous extinction was likely the result of a slightly elevated extinction rate combined with a mildly depressed origination rate (Briggs, 1991).

The background rate of extinction and the rate of mass extinction for nonmarine tetrapods, such as amphibians, appear to be statistically indistinguishable (Benton, 1985). The K-T rate reported for amphibians is 33–43% (Clemmens, 1986; Raup, 1994). The background extinction rate for all organisms is 0.5–5 extinctions per year (IUCN et al., 2006). Recent studies suggest that ancient extinction rates may range from 6–15% lower than previously believed (McKinney, 1995). Many paleontologists believe that ancient amphibian and mammalian extinctions behaved similarly (Clemmens, 1986). The mammalian background extinction rate is about one species per year (May et al., 1995). Amphibian preservation potential is unknown, but it is probably much lower than that of mammals (Valentine, 1990). This may be in part caused by the low preservation potential of soft/cartilaginous body tissues, which make up a large portion of the amphibian skeleton (Newell, 1959; Signor, 1990). Relative to mammals, many amphibians are small; thus, their skeletons are more readily disarticulated and more susceptible to destruction by mechanical forces such as erosion (Newell, 1959). Consequently, the mammalian preservation potential should be a conservative estimate of the amphibian preservation potential because it would predict far fewer unrecorded species extinctions than would the authentic amphibian value. The mammalian preservation potential is about 67% (95% CI = 65–70%; Regan et al., 2001).

Although many perspectives on the accuracy, precision, and validity of paleontologic evidence exist (Jablonsky, 1994; McKinney, 1995), these data represent the only record of past origination and extinction and are considered an adequate metric for examining biodiversity patterns (Valentine, 1990). Young taxa appear to be more susceptible to extinction than older groups, possibly because of their relatively low species richness and geographic ranges (Boyajian, 1991). Virtually all modern extant taxa have low familial origination and extinction probabilities (Gilinsky, 1994). There tends to be about a 10 million-year lag between extinction and the ensuing recovery via origination (Kirchner and Weil, 2000). This suggests that high extinction rates of modern taxa warrant significant cause for concern because these groups have a low probability of going extinct in the first place and their corresponding recovery from extinction can require millennia.

Despite the attention paid to amphibian declines, extinction occurs regularly and naturally throughout geologic history (see citations in Blaustein et al., 1994). This makes studies on how current amphibian declines compare with those in the amphibian fossil record of vital importance. By understanding whether current extinction rates are encompassed in the naturally occurring noise of historical extinctions, only minor perturbations outside of the normal variation, or extreme ventures beyond the predicted variation, we are better able to understand and identify their proximate and ultimate causes. These causes can then be evaluated, mitigation strategies devised, and conservation practices employed for disappearing groups.

Furthermore, by understanding how current extinction rates compare to those estimates from geologic history, we can more judiciously interpret whether and how human activities might interact with current population trends (Richman et al., 1988; Jablonsky, 1994). Human activities are generally believed to exacerbate extinction risks (Richman et al., 1988). Here I use fuzzy arithmetic to compare published estimates for current and past amphibian diversity and extinction to provide a frame of reference for comparison to the global amphibian decline.

Materials and Methods

Comparisons between current and past extinction rates were made using traditional and fuzzy arithmetic. Fuzzy arithmetic is a conservative, nonsubjective generalization of interval analysis that is used for dealing with uncertainty, and requires fewer data than alternative methods like Monte Carlo simulations (Silvert, 1997, 2000; Ferson et al., 1999). It is applicable to all kinds of uncertainty, without the need for subjective interpretations used in Monte Carlo approaches, and it is based on a consistent axiomatic system that is different from that used in probability theory (Ferson et al., 1999). Fuzzy arithmetic rates data (x-axis) based on degrees of possibility called membership values (y-axis) where $y = 0$ = lowest possibility and $y = 1$ = highest possibility. If the graphical representation is a triangle, then only one value has the membership value $y = 1$. If the representation is a trapezoid, then a series of values across the top of the polygon are equally possible and all have membership values $y = 1$. All other x-values have decreasing membership values (i.e., possibilities, as y approaches zero). Fuzzy arithmetic is particularly useful where high levels of uncertainty such as ambiguity, nonspecificity, discord, and fuzziness exist (Klir and Yuan, 1994). Paleontological information is often incomplete and difficult to interpret; as such, it is plagued by uncertainty (Jablonsky, 1994; McKinney, 1995; Alroy, 2002). Fuzzy arithmetic is specifically useful for dealing with this kind of uncertainty and the associated incomplete data sets (Silvert, 1997, 2000; Ferson et al., 1999), making it well suited for analyzing the amphibian fossil record.

The below equations were used to calculate the following statistics (Regan et al., 2001) using data from Table 1: (1) the minimum percentage of extant amphibians that have become extinct in recent times

$$\left(N_{\text{recent amphibian extinctions}} / N_{\text{extant amphibian species}}\right) \times 100; \quad (1)$$

(2) the number of amphibian extinctions since 1500 AD (505 observation years) using the invertebrate background rate and observed extant diversity

$$\left(N_{\text{extant amphibian species}} / N_{\text{extant species recorded}}\right) \times \left(r_{\text{background}}\right)\left(\mathrm{T}_{\text{obs}}\right); \quad (2)$$

(3) the number of amphibian extinctions using

TABLE 1. Data on current amphibian extinction, extant diversity, and background extinction rates. These values were obtained from IUCN (1994) unless otherwise indicated.

Statistic	Estimate
Number of recent amphibian extinctions ($N_{\text{recent amphibian extinctions}}$)	35–130
Number of observation years (T_{obs})	505
Number of extant amphibian species ($N_{\text{extant amphibian species}}$)	5,918
Number of extant species (recorded) ($N_{\text{extant species recorded}}$)	1,400,000
Number of extant species (estimated) ($N_{\text{extant species estimated}}$)	10,000,000
''Fossil'' background rate ($r_{\text{background}}$)	1 species per year (May et al., 1995), 0.5–5 species/year
Fossil marine invertebrate background rate ($r_{\text{invertebrate background}}$)	0.25 extinctions per species million years
Preservation rate of mammals (P_{mammal})	67% [99% CI = 65–70%] (Regan et al., 2001)
K-T extinction rate ($R_{\text{K-T}}$)	33–43% (Clemmens 1986, Raup 1994)

the estimated extant diversity

$$\left(N_{\text{extant amphibian species}}/N_{\text{extant species estimated}}\right) \times \left(r_{\text{background}}\right)\left(T_{obs}\right); \quad (3)$$

(4) the minimum rate of amphibian extinction per million years

$$\left(N_{\text{recent amphibian extinctions}}/T_{obs}\right) \times 10^6; \quad (4)$$

(5) the per taxon rate of amphibian extinction

$$\left(N_{\text{recent amphibian extinctions}}/N_{\text{extant amphibian species}}\right) \times \left(10^6/T_{obs}\right); \quad (5)$$

and (6) the comparison of current extinction rates to background rates

$$\left[\left(N_{\text{amphibian extinctions}}\right)(0.67) \div \left(N_{\text{extant amphibian species}}\right)\left(P_{\text{mammal}}\right)\right] \times \left(10^6/T_{obs}\right)\left(1/R_{K-T}\right). \quad (6)$$

Following published methods (Ferson et al., 1999; Regan et al., 2001), I constructed fuzzy numbers for each integer estimate of amphibian diversity and extinction based on the degree of uncertainty reported in the published data. Where uncertainty for point estimates was unavailable, I used an error rate of ± 10% (Regan et al., 2001). After all of the fuzzy numbers were produced, extinction estimates were calculated using equations [1]–[5] above and the reported data (Table 2). All fuzzy calculations were performed using RAMAS RiskcalcTM 3.0 (Ferson et al., 1999). Finally, I used equation [6] to compare the estimated extinction rates since 1500 and since 1980 to published estimates of the background amphibian extinction rate and the number of species currently in danger of extinction.

RESULTS

Standard Point Estimates.—At least 0.59% of extant amphibians have become extinct since 1500. Based on the invertebrate background rate and the observed extant diversity, 2.1 amphibian extinctions would be expected during 505 observation years. Using the invertebrate background rate and the estimated extant diversity,

TABLE 2. Fuzzy number estimates for current amphibian extinction, extant diversity, and background extinction rates.

Statistic	Fuzzy number estimate
K-T extinction rate (Clemmens 1986, Raupp 1994)	[0.33, 0.43]
Extant amphibian species	[5,326, 5,918, 6,510]
Minimum amphibian extinctions since 1500	[31, 35, 38.5]
Maximum amphibian extinctions since 1500	[148.5, 165, 182]
Amphibian extinctions since 1500	[31, 35, 165, 182]
Minimum amphibian extinctions since 1980	[8, 9, 10]
Maximum amphibian extinctions since 1980	[98, 109, 120]
Amphibian extinctions since 1980	[8, 9, 109, 120]
Amphibian species possibly extinct since 1980 plus those in danger of extinction according to IUCN	[1,715, 1,905, 2,096]
''Fossil'' background rate ($r_{\text{background}}$)	[0.5, 1, 5]
Preservation potential of mammals	[65, 67, 70]

no more than 0.299 amphibian species should go extinct during 505 yr. Approximately 69,307 amphibian extinctions are expected per million years. This per taxon rate of amphibian extinction is about 12 amphibian species every million years. The maximum point estimate for amphibian extinctions is 2.79% in the past 505 yr. The maximum rate of amphibian extinctions per million years is 326,732 species and the maximum per taxon rate of amphibian extinction 55.21 species. Using point estimates and standard arithmetic the minimum current extinction rate is 27 times greater than the highest point estimate of background extinction.

Fuzzy Estimates for Post-1500 Data.—Based on the most conservative rates available, the fuzzy estimate for the minimum percentage of extant amphibians that became extinct since 1500 is 0.48–0.73% (28–43 species). The fuzzy estimate for the minimum percentage of extant amphibians that have gone extinct since 1500 based on the higher extinction estimates is 2.3–3.4% (134–201 species).

The overall fuzzy estimate for the minimum percentage of extant amphibians that became extinct since 1500 is 0.48–3.4% (28–201 species). The overall fuzzy estimate for amphibian extinctions expected during 505 yr (using the invertebrate background rate and observed extant diversity) is 1–11, with the best estimate about two extinctions. The number of amphibian extinctions predicted when using the invertebrate background extinction rate and the estimated extant diversity is 0.13–1.64 species every 505 yr with the best estimate being 0.30 species.

The minimum number of amphibian extinctions per million years based on the most conservative value is 61,386–77,227 species with the best estimate being 69,307 species. The minimum number of amphibian extinction per million years based on the higher estimate is 293,069–360,396 species with the most possible estimate being 326,733 species. The overall minimum number of amphibian extinctions per million years is 61,386–360,396 species with the best estimate being 69,307–326,733 species. The minimum per taxon amphibian extinction rate during the last million years is 10–13 extinctions with the best estimate being 12. The maximum per taxon amphibian extinction rate during the last million years is 49–61 extinctions with the best estimate being 55 extinctions. The overall per taxon amphibian extinction rate during the last million years is 10–61 extinctions with the best estimate being 11–55 extinctions.

The smaller fuzzy estimate of the extinction rate for amphibians during the past 505 yr is at least 21–45 times higher than the background extinction rate reported for this group. The best estimate is 27–35 times greater than the background amphibian extinction rate. The larger fuzzy estimate of the extinction rate for amphibians over the past 505 yr is at least 100–211 times higher than the background extinction rate reported for this group with the best estimate being 27–35 times higher than expected. The overall fuzzy estimate of the extinction rate among amphibians over the past 505 yr is at least 21–211 times higher than the background extinction rate reported for this group. The most likely background extinction rate is 27–167 times the reported background extinction rate for amphibians.

Fuzzy Estimates for Post-1980 Data.—Based on the most conservative rates, the fuzzy estimate for the minimum percentage of extant amphibians that went extinct since 1980 is 0.12–0.19% (7–11 species). Based on the less conservative rates, the fuzzy estimate for the minimum percentage of extant amphibians that became extinct since 1980 is 1.50–2.25% (88–133 species).

The overall fuzzy estimate for the minimum percentage of extant amphibians that went extinct since 1980 is 0.12–2.25% (7–133 species). The overall fuzzy estimate for amphibian extinctions expected during 26 yr (using the invertebrate background rate and observed extant diversity) is 0.50–0.60 extinctions every 26 yr, with the best estimate about 0.1 extinctions. The number of amphibian extinctions predicted when using the invertebrate background extinction rate and the estimated extant diversity is 0.007–0.08 species every 26 yr with the best estimate being 0.02 species.

The smaller fuzzy estimate of the extinction rate among amphibians since 1980 is at least 105–225 times higher than the background extinction rate reported for this group with the best estimate being 136–177 times greater than expected. The larger fuzzy estimate of the amphibian extinction rate since 1980 is at least 1,288–2,707 times higher than the background extinction rate reported for amphibians with the best estimate being 1,647–2,147 times greater than expected. The overall fuzzy estimate for the extinction rate among amphibians since 1980 is at least 105–2,707 times greater than the background rate for amphibians, with the best estimate being 136–2,147 times higher than the background extinction rate.

If the 1,896 amphibian species we believe to be in danger of extinction (Stuart et al., 2004) are added to the post-1980 extinction estimates, then the impending rate of extinction will be 25,039–45,474 times greater than the amphibian background extinction rate. The best estimate for this extinction rate is 28,792–39,487 times the background amphibian extinction rate.

Discussion

Fuzzy Results versus Standard Estimates.—Fuzzy sets provide more useful estimates of ancient extinctions than point estimates because of the high degree of uncertainty in paleontological data. This method is especially useful when comparing extinction rates. We do not know the true number of extant and extinct species; thus, we must deal with estimates. By providing series of values with their associated degree of possibility/uncertainty (i.e, membership values), fuzzy sets allow us to consider estimates that may be true and those that are marginally possible. Standard point estimates and probabilities do not provide this flexibility, thus, proven less useful for paleontological analyses (Ferson et al., 1999).

Standard arithmetic suggests 0.59% of amphibians became extinct since 1500, whereas fuzzy estimates provide a range from 0.48–3.4%. The fuzzy estimate is much more useful because it provides a range of possible extinction rates (0.59–3.40%) with an associated estimate (0–1) of possibility. The point estimate provided by standard arithmetic is part of the fuzzy set of possible values I calculated; however, a large number of equally possible and larger percentages are predicted as well. This is important because we do not know for certain how many species exist, how many went extinct, or the probabilities of extinction associated with all groups. The fuzzy approach allows us to consider even the least likely possibilities for prediction and estimation without concern for this uncertainty and lacking information.

Extinctions since 1500 versus Background Amphibian Extinction Rate.—The minimum percentage of extant amphibians that went extinct in the past 505 yr provides concern regardless of how much uncertainty in the data is actually true. The extinction estimate based on standard arithmetic is 0.59%, whereas the fuzzy estimate suggests a range of possible percentages (0.48–3.40%) depending on how much uncertainty is real.

During a 505-yr period, we would expect only 0.13–11 extinctions, with the best estimate (0.30–2 extinctions) being at the low end of this range. The number of amphibian extinctions in the past 505 yr exceeds the background rate. In fact, the number of species that we believe went extinct since 1500 more closely approximates the per taxon extinction rate (11–55) during a million years.

Extinctions since 1980 versus Background Amphibian Extinction Rate.—Most post-1500 extinctions (7–133) occurred since 1980 explaining why these more recent extinction rates are much more extreme than during the last 505 yr. Based on the geologic record, we should only see 0.007–0.60 extinctions since 1980. Current extinction rates are clearly far higher than what is normally expected. This extinction rate is at least 105 times that of the background extinction rate for amphibians; however, this figure has a low possibility. Current extinction rates are most likely 136–2707 times greater than the background amphibian extinction rate. These are staggering rates of extinction that are difficult to explain via natural processes. No previous extinction event approaches the rate since 1980 (Benton and King, 1989).

Current Amphibian Declines versus the Amphibian Background Extinction Rate.—Despite the catastrophic rates at which amphibians are currently going extinct, these are dwarfed by expectations for the next 50 yr (Fig. 1). If the figure provided by Stuart et al. (2004) is true (but see Pimenta et al., 2005; Stuart et al., 2005), one-third of the extant amphibians are in danger of extinction. This portends an extinction rate of 25,000–45,000 times the expected background rate. Episodes of this stature are unprecedented. Four previous mass extinctions could be tied to catastrophic events such as super volcanoes and extraterrestrial impacts that occur every 10 million to 100 million years (Wilson, 1992). The other mass extinction seems to be tied to continental drift of *Pangea* into polar regions leading to mass glaciation, reduced sea levels, and lower global temperatures (Wilson, 1992). The current event far exceeds these earlier extinction rates suggesting a global stressor(s), with possible human ties.

The fossil record indicates that early amphibian groups show faster turnover rates than later groups (Valentine, 1990) and that modern taxa have lower extinction and origination rates than those of the geologic past (McKinney, 1995). This makes rapidly growing extinctions in modern times even less expected and more problematic. The rate of extinction has clearly accelerated since 1500. With this newly refined comparison of ensuing extinction to that observed in the fossil record, it is difficult to speak of amphibian declines and much more accurate to refer to this die-off as a global amphibian extinction event.

Concluding Remarks.—These data indicate that the general trend of amphibian extinction suggests catastrophic future losses and uncertain opportunity for recovery. It is unfortunate that less attention is paid to amphibians than to many other groups (McKinney, 1998; McCallum and McCallum, 2006; Mendelson, 2006). Biodiversity preservation must pay careful attention to factors, including natural history information, that are critical to the survivability of all taxa (Mode and Jacobsen, 1987; Ricketts et

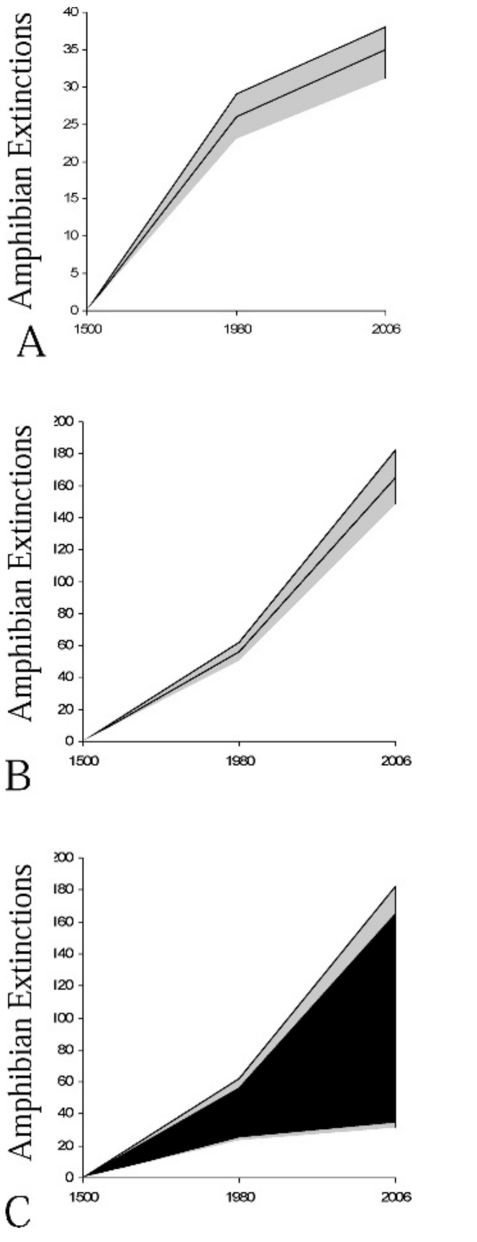

FIG. 1. The acceleration of amphibian extinction rates since 1500 based on the lower (A), higher (B), and overall (C) fuzzy estimate. The black line/area represents values with Possibility = 1. The areas shaded in gray represent fuzzy values with Possibility < 1 but > 0.

al., 2005). It is believed that extinct species probably lingered on for decades before completely disappearing (Primm, 2002), suggesting that amphibian conservation has reached a level of urgency requiring immediate attention (Stuart et al., 2004; Bury, 2006; Fitch, 2006). If we continue on our current course, the accelerating loss of amphibians and other groups can only lead to losses in human comfort and quality of life, not to mention ecosystem function. How many more rivets are we going to lose, and can we stay airborne?

> "'*Don't worry,' he assures you. 'I'm certain the manufacturer made this plane much stronger than it needs to be, so no harm's done. Beside, I've taken lots of rivets from this wing and it hasn't fallen off yet.*" (Erlich and Erlich, 1981).

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APPENDIX 1

The minimum percentage of extant amphibians that have become extinct in recent times is

$$[1] = (35/5{,}918) \times 100 = 0.59\%$$

of extant amphibians went extinct since 1500.

The number of amphibian extinctions expected during 505 observation years (using the invertebrate background rate and observed extant diversity) is

$$[2] = (5{,}918)/\left(1.4 \times 10^6\right)(1)(505) = 2.13$$

amphibian extinctions expected in 505 yr.

The number of amphibian extinctions expected using the invertebrate background rate and the estimated extant diversity is

$$[3] = \left(5{,}918/10 \times 10^6\right)(1)(505) = 0.299$$

amphibian species extinctions expected in 505 yr.

The minimum rate of amphibian extinction per million years is

$$[4] = (35/505) \times 10^6 = 69{,}307 \text{ species}/10^6 \text{ yr}.$$

The minimum per taxon rate of amphibian extinction is

$$[5] = (35/5{,}918) \times 10^6/505 = 12$$

amphibian species extinctions expected/million yr.

The maximum percentage of recently extant amphibians that went extinct is

$$[1] = (165/5{,}918) \times 100 = 2.79\%$$

extinction.

The maximum rate of amphibian extinctions per million years is

$$[4] = (165/505) \times 10^6 = 326{,}732$$

amphibian species extinctions.

The maximum per taxon rate of amphibian extinctions is

$$[5] = (165/5{,}918)\left(10^6/505\right) = 55.21$$

amphibian species extinctions/million species yr.

The minimum current extinction rate is 27 times greater than the higher background extinction rate.

$$[6] = [(35)\ (0.67)/(5{,}918)\ (0.67)]\left(10^6/505\right)(1/0.43) = 27.24.$$

Based on the most conservative rates, the fuzzy estimate for the minimum percentage of extant amphibians that became extinct since 1500 is

$$[1] = ([31, 35, 39]/[5{,}326, 5{,}918, 6{,}510]) \times 100 = [0.4761904, 0.591416, 0.7322569].$$

The fuzzy estimate for the minimum percentage of extant amphibians that went extinct since 1500 based on the higher estimates is

$$[1] = ([31, 35, 165, 182]/[5{,}326, 5{,}918, 6{,}510]) \times 100 = [0.4761904, 0.591416, 2.788105, 3.417199].$$

The overall fuzzy estimate for the minimum percentage of extant amphibians that became extinct since 1500 is

$$[2] = ([5{,}326, 5{,}918, 6{,}510])/\left(1.4 \times 10^6\right)([0.5, 1, 5])(505) = [0.9605821, 2.134707, 11.74125].$$

The overall fuzzy estimate for amphibian extinctions expected during 505 yr (using the invertebrate background rate and observed extant diversity) is

$$[3] = ([5{,}326, 5{,}918, 6{,}510])/\left(10 \times 10^6\right)(0.5, 1, 5)(505) = [0.1344815, 0.298859, 1.643775].$$

The number of amphibian extinctions predicted when using the invertebrate background extinction rate and the estimated extant diversity is

$$[4] = ([31, 35, 39]/505) \times 10^6 = [61386.13, 69306.93, 77227.73].$$

The minimum number of amphibian extinctions per million years based on the most conservative value is

$$[4] = ([148, 165, 182]/505) \times 10^6 = [293069.3, 326732.6, 360396.1].$$

The minimum number of amphibian extinction per million years based on the higher estimate is

$$[4] = ([31, 35, 165, 182]/505) \times 10^6 = [61386.13, 69306.93, 326732.7, 360396.1].$$

The overall minimum number of amphibian extinction per million years is

$$[5] = ([31, 35, 39]/5{,}918)\left(10^6/505\right) = [10.37278, 11.7112, 13.04964].$$

The minimum per taxon amphibian extinction rate during the last million years is

$$[5] = ([148, 165, 182]/5{,}918)\left(10^6/505\right) = [49.52166, 55.20998, 60.8983].$$

The maximum per taxon amphibian extinction rate during the last million years is

$$[5] = ([31, 35, 165, 182]/5{,}918)\left(10^6/505\right) = [10.37278, 11.7112, 55.21, 60.8983].$$

The overall per taxon amphibian extinction rate during the last million years is

$$[6] = [([31, 35, 39])(0.67)/([5{,}326, 5{,}918, 6{,}510]) \times ([0.65, 0.67, 0.70])]\left(10^6/505\right)(1/[0.33, 0.43]) = [20.98928, 27.23534, 35.48849, 45.29182].$$

The smaller fuzzy estimate of the extinction rate for amphibians during the past 505 yr is

$$[6] = [([148, 165, 182])(0.67)/([5{,}326, 5{,}918, 6{,}510]) \times ([0.65, 0.67, 0.70])]\left(10^6/505\right)(1/[0.33, 0.43]) = [100.2068, 128.3953, 167.303, 211.3618].$$

The larger fuzzy estimate of the extinction rate for amphibians over the past 505 yr is

$$[6] = [([31, 35, 165, 182])(0.67)/([5{,}326, 5{,}918, 6{,}510]) \times ([0.65, 0.67, 0.70])]\left(10^6/505\right)(1/[0.33, 0.43]) = [20.98928, 27.23534, 167.3031, 211.3618].$$

The overall fuzzy estimate of the extinction rate among amphibians over the past 505 yr is

$$[1] = ([8, 9, 10]/[5{,}326, 5{,}918, 6510]) \times 100 = [0.1228878, 0.1520784, 0.1877582].$$

Based on the most conservative rates, the fuzzy estimate for the minimum percentage of extant amphibians that went extinct since 1980 is

$$[1] = ([98, 109, 120]/[5{,}326, 5{,}918, 6{,}510]) \times 100 = [1.505376, 1.841838, 2.253099].$$

Based on the less conservative rates, the fuzzy estimate for the minimum percentage of extant amphibians that became extinct since 1980 is

$$[1] = ([8, 9, 109, 120]/[5{,}326, 5{,}918, 6510]) \times 100 = [0.1228878, 0.1520784, 1.841839, 2.253099].$$

The overall fuzzy estimate for the minimum percentage of extant amphibians that went extinct since 1980 is

$$[2] = ([5{,}326, 5{,}918, 6{,}510])/\left(1.4 \times 10^6\right)([0.5, 1, 5])(26) = [0.04945569, 0.1099056, 0.6045].$$

The overall fuzzy estimate for amphibian extinctions expected during 26 yr (using the invertebrate background rate and observed extant diversity) is

$$[3] = ([5{,}326, 5{,}918, 6{,}510])/\left(10 \times 10^6\right)([0.5, 1, 5])(26) = [0.0069238, 0.0153868, 0.08463].$$

The number of amphibian extinctions predicted when using the invertebrate background extinction rate and the estimated extant diversity is

$$[6] = [([8, 9, 10])(0.67)/([5{,}326, 5{,}918, 6{,}510]) \times ([0.65, 0.67, 0.70])]\left(10^6/26\right)(1/[0.33, 0.43]) = [105.2067, 136.0271, 177.2476, 225.5658].$$

The smaller fuzzy estimate of the extinction rate among amphibians since 1980 is

$$[6] = [([98, 109, 120])(0.67)/([5{,}326, 5{,}918, 6{,}510]) \times ([0.65, 0.67, 0.70])]\left(10^6/26\right)(1/[0.33, 0.43]) = [1288.783, 1647.44, 2146.665, 2706.79].$$

The larger fuzzy estimate of the amphibian extinction rate since 1980 is

$$[6] = [([8, 9, 109, 120])(0.67)/([5{,}326, 5{,}918, 6{,}510]) \times ([0.65, 0.67, 0.70])]\left(10^6/26\right)(1/[0.33, 0.43]) = [105.2067, 136.0271, 2146.666, 2706.79]$$

The overall fuzzy estimate for the extinction rate among amphibians since 1980 is

$$[6] = [([1{,}904, 1{,}905, 2{,}005, 2{,}016])(0.67)/ \times ([5{,}326, 5{,}918, 6{,}510])([0.65, 0.67, 0.70])] \times \left(10^6/26\right)(1/[0.33, 0.43]) = [25039.2, 28792.39, 39486.88, 45474.07]$$