Human perception relates to when endangered species are listed

Christopher A Lepczyk[1*], Brian T Klingbeil[1], Rebecca A Christoffel[2], Daniel T Rutledge[3], and Curtis H Flather[4]

The species endangerment listing process is governed not solely by causal factors but also by human perception, particularly as it relates to observability. Because human perception is important in species detection, we hypothesized that ecological indicators associated with human perception would change noticeably over time. Testing our hypothesis on species listed under the US Endangered Species Act, we found that – in general and across (not within) different taxa – body mass and geographic range of listed species decreased over time and that animals that produced vocalizations and exhibited grouping behavior were listed earlier than silent and solitary animals. Specifically, since the year of their listing, the body mass of birds, mammals, and reptiles decreased, whereas the body mass of amphibians increased; likewise, the geographic range of insects, mammals, and plants contracted, whereas the geographic range of amphibians, bivalves, birds, and fish slightly expanded. Our results demonstrate a temporal shift in endangered species listings, suggesting that approaches to listing species may need to be reevaluated and methodologically revised.

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The Endangered Species Preservation Act of 1966 was the first law that authorized the listing of imperiled species in the US. In the years that followed, Congress continued to refine the law, with the inclusion of additional taxonomic groups and more comprehensive protections for endangered species and their habitats. These revisions culminated in the Endangered Species Act (ESA) of 1973 (16 USC § 1531 *et seq*), the primary objectives of which are to "provide a means whereby the ecosystems upon which endangered species and threatened species depend may be conserved" and "provide a program for the conservation of such endangered species and threatened species" (16 USC § 1532). In addition, the ESA requires the US Fish and Wildlife Service (USFWS) and the National Marine Fisheries Service to base listing decisions "solely on the best scientific and commercial data available" (ESA sec 4[b][1][A]; Rohrman 2003). Ideally, with respect to listing decisions, ignoring characteristics associated with societal preferences, cultural or economic value, and species appearance or behavior – and basing decisions only on the best scientific and commercial data available regarding the current status, threats, and existing protections – would eliminate bias. Eliminating bias would then lead to any and all species being listed when they meet the criteria identified in the ESA. But what if ignoring these characteristics has had the unintentional consequence of biasing the availability of the best scientific and commercial data, thereby limiting the effectiveness of the ESA? Such a possibility exists given that listing species as threatened and endangered is a socioecological process influenced by a variety of factors.

Ecologically, species endangerment is related to such factors as habitat loss, introduction of novel species, and pollution (Czech and Krausman 1997; Wilcove *et al*. 1998). Likewise, socioeconomic factors such as the importance we place on the species economically, culturally, or socially (eg whether a species is considered charismatic) (Metrick and Weitzman 1996; Bellon 2019) have been related to species listed as endangered. Furthermore, species perceived to be of greater importance or that are more highly valued, such as birds and mammals, typically receive more attention (eg Davies *et al*. 2018), which in turn leads to better information (Clark and May 2002). One additional factor that crosses the socioecological spectrum and may influence the listing process is human perception. In particular, human perception likely influences the petitioning process and characterization of species endangerment due to such factors as whether we know if a species exists and how easily a species can be detected and assessed. A case in point are invertebrates, which far outnumber vertebrate species but are comparatively poorly known, studied, and represented in endangered species lists (Cardoso *et al*. 2011). Similarly, species traits like vocal communication or congregating behaviors are likely to influence detection probabilities of scientific surveys and casual observations by the general public more so than a plant or invertebrate with a highly restricted distribution, potentially biasing the availability of scientific and commercial data.

Although human perception is clearly important in the listing process, it has not been formally evaluated. Specifically, there is a lack of data and agreement on suitable measures of human perception, which has precluded formal assessment of the role human perception plays in scientific decision making,

[1]*College of Forestry, Wildlife and Environment, Auburn University, Auburn, AL* [*]*(lepczyk@auburn.edu);* [2]*Christoffel Conservation, Madison, WI;* [3]*BIJ 12, Utrecht, the Netherlands;* [4]*USDA Forest Service, Rocky Mountain Research Station, Fort Collins, CO*

especially for observations made over large geographic areas and long periods of time. Formal assessments in which human perception of nature or species conservation was considered have generally been restricted to studies of landscape quality assessment (Daniel 2001), public attitudes and valuations of individual species (Knight 2008), ecosystem services (Asah *et al.* 2014), and climate change (Semenza *et al.* 2008). However, little systematic research exists on how human perception may influence the listing process.

Research on sampling methodology indicates that species detection depends on species' ecological characteristics, human perception, and their interaction. For instance, large-bodied animals and herds are detected more readily than small-bodied or solitary animals (Jachmann 2002; Fletcher and Hutto 2006). Thus, body size could lead to a disproportionate representation of, for example, large-bodied birds on threatened and endangered species lists as compared to smaller birds (Gaston and Blackburn 1995). The known differences in detection rates, coupled with the need to understand details about species' ecologies to assess their status, have spurred ecologists to improve species detection. New knowledge has been gained through various mechanisms, such as enhanced, coordinated, and long-term monitoring programs (eg the North American Breeding Bird Survey) and technological advancements (eg telemetry, camera traps, environmental DNA [eDNA]) (Possingham *et al.* 2002; Franklin *et al.* 2019).

Increases in knowledge about species over time coupled with our known perception biases lead to expectations of a predictable, temporal relationship between human perception of ecological factors and patterns or trends in species endangerment. Therefore, we selected four proxies of human perception that exemplify ecological factors known to influence detection in ecological studies: body mass, geographic range, animal calling (vocalization), and social or congregating behavior. These four factors were not selected based on natural history attributes, but rather on the likelihood of observing objects based on size, occurrence, and audibility. Consequently, some factors (body mass, geographic range) may also correlate with traits used to assess vulnerability to extinction (Fritz *et al.* 2009; Chichorro *et al.* 2019). On the basis of these factors, we hypothesized that humans more easily detect and assess the status of species that are large bodied, have broader geographical ranges, that vocalize, and that congregate in groups. As such, we predicted that large-bodied, vocal, grouping, and more wide-ranging species would be listed earlier. To test this hypothesis, we examined the relationships between body mass, range size, vocalization, congregation, and the year a species was listed under the ESA.

Methods

We compiled and edited a database of species listed as threatened or endangered from March 1967 through October 2018 under the ESA, including (1) year of listing (USFWS 2018); (2) area of species geographic range in the US (USFWS 2018); (3) body mass (in grams) of birds, mammals, reptiles, and amphibians (WebPanel 1); and (4) calling and congregating behavior for mammals, birds, reptiles, and amphibians from recovery plans and additional sources (WebPanel 1). We used 1967 as the first year for our analysis because it includes species listed under the ESA's predecessor (the Endangered Species Preservation Act) (Flather *et al.* 1994). Only species known to inhabit the conterminous US, Alaska, and Hawaii were included. We also considered species that were delisted due to recovery or extinction (but not species that were delisted due to original data in error), resulting in a total of 1533 listed species.

We calculated species range size as the sum of the areas (in square kilometers) in which a species was/is known to occur based on range polygonal boundaries for species as delimited by the USFWS (https://ecos.fws.gov/ecp). These data reflect a current estimate of the geographic range of each species, where USFWS considers "current" to be between 1972 and 2018; data (ie occurrence and environmental data) that occur during this time period can therefore be used for the construction of current ranges (https://ecos.fws.gov/docs/SR_SOP/SDM_SOP_Final_14Nov2019.pdf). This range is equivalent to the range at the time of listing for some of the species but also includes changes and refinements based on additional research. We determined whether geographic range and body mass data were normally distributed using the Shapiro–Wilk normality test. After inspecting diagnostic plots, we also used the Fligner-Killeen test of homogeneity of variances. Geographic range (Shapiro–Wilk, $W = 0.100$, $P < 0.001$) and body mass (Shapiro–Wilk, $W = 0.117$, $P < 0.001$) were not normally distributed and were therefore $\log_{10}$ transformed to address assumptions of normality. Variances of associations between $\log_{10}$ transformed geographic range (Fligner-Killeen, $\chi^2 = 1181.9$, $P = 1.0$) and body mass (Fligner-Killeen, $\chi^2 = 185.51$, $P = 0.244$) with listing year were homogeneous and did not require corrective measures. We analyzed how body mass and geographic range changed over the listing period (1967–2018) using general linear models in R (R Core Team 2021), with consideration of taxonomic grouping. Because islands harbor lower species richness and are unique systems relative to continental areas, we also included geographic context (continental versus Hawaiian) as a covariate. For each model, we calculated Akaike information criterion (AIC) corrected for small sample size (AICc) (Burnham and Anderson 2002). We compared models using the difference in AICc between a given model and the best (lowest AICc) model. Models with a difference of AICc <2 were considered equally supported by empirical evidence. We calculated AIC weights (w_i) for each model to represent the weight of the evidence that a particular model is the best model, given the data and the set of candidate models. AICc and associated weights were calculated with the *AICcmodavg* package in R. We analyzed year of listing as a function of two behaviors related to human perception: calling and congregating for a species where data were available (Table 1). Each behavior was treated as a binary variable (calling versus silent; congregating versus solitary) in a two-sample *t* test with Welch correction for unequal

Table 1. First year a species from a particular taxonomic group was listed (listing year) and sample sizes of taxonomic groups included in analyses of ecological surrogates (mass, group, and call) used to assess the role of human perception in the Endangered Species Act listing process

Group	Listing year	Listing year (*n*)	Mass (*n*)	Group (*n*)	Call (*n*)
Amphibian	1967	29	13	16	29
Arachnid	1988	12	–	–	–
Bird	1967	88	87	80	88
Bivalve	1976	91	–	–	–
Crustacean	1978	28	–	–	–
Fish	1967	143	–	–	–
Insect	1976	85	–	–	–
Mammal	1967	88	88	84	88
Plant	1977	883	–	–	–
Reptile	1967	36	25	21	36
Snail	1978	48	–	–	–

sample sizes. Because our goal was to test the hypothesis relating proxies of human perception to species listing over time, we only modeled linear relationships and not more complex nonlinear relationships or stepwise selection procedures.

Results

Body mass and geographic range size had significant negative relationships with time of listing when all species were included (Figure 1). The best models included variables for taxonomic group and continent (Table 2). Relationships for continental and Hawaiian taxa exhibited similar trends (WebFigures 1 and 2). When comparing behaviors related to human perception, animals that vocalized were listed significantly earlier (1981 ± 2.6 [listing year ± 95% confidence interval]) than silent animals (1990 ± 3.2) (t_{206} = –4.2, $P<0.001$), and congregating animals were listed earlier (1981 ± 2.9) than solitary animals (1987 ± 3.4) (t_{178} = –2.2, P = 0.03). Considerable variation existed in the first year a species from a particular taxonomic group was listed (Figure 2), as did the strength and direction of relationships between geographic range size and year of listing (Figures 1 and 2). Specifically, body mass of mammals, birds, and reptiles decreased with year of listing, whereas that of amphibians increased (WebFigure 2a). Likewise, geographic range size decreased with year of listing for insects, mammals, and plants; did not change for arachnids, crustaceans, reptiles, and snails; and increased for amphibians, birds, bivalves, and fish (Figure 2).

Discussion

Overall, body mass and geographic range size had significant negative correlations with time of listing under the ESA, and animals that call and congregate were listed earlier, although not all individual taxa exhibited both relationships. These results provide general support for our hypothesis that humans more readily perceive the status of more conspicuous species. Furthermore, these findings suggest that human perception plays a role in species listing: initial species were larger and easier to identify or observe, but listings over time have gradually shifted to smaller and less conspicuous species. This pattern contrasts with recent evidence identifying a bimodal relationship between body size and extinction risk for vertebrates (Ripple *et al*. 2017), suggesting that biases associated with perception may have led to a failure to protect species in need.

In comparing body mass relationships between Hawaii and the continental US, only birds contained more than three species for analysis. Although Hawaiian birds weighed less, they followed the same negative listing trajectory as mainland birds. Moreover, the average Hawaiian bird was listed more than a decade earlier than mainland birds (1968.5 versus 1979) (*t* test,

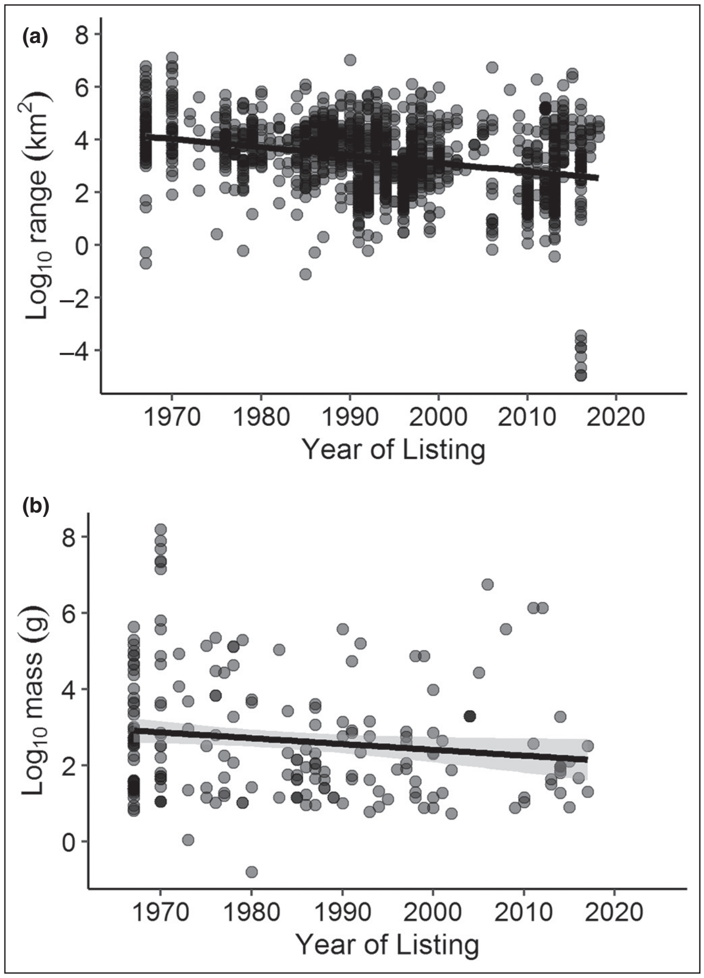

Figure 1. (a) Changes in geographic range (in square kilometers) by listing year for species within all eleven major taxonomic groups combined. (b) Changes in body mass (in grams) by listing year for amphibian, bird, mammal, and reptile species combined. Gray circles and black lines in (a) and (b) represent points of overlap that are slightly offset and linear regressions, respectively; shaded area in (b) denotes standard error.

Table 2. Model results of species listing year related to body mass and geographic range

Model	R^2	K	AICc	ΔAICc	w_i
Body mass					
Listyear ~ Mass	0.02	3	1769	27.0	0.00
Listyear ~ Mass + Group	0.15	6	1746	3.4	0.08
Listyear ~ Mass + Group + Mass * Group	**0.18**	**9**	**1744**	**1.8**	**0.18**
Listyear ~ Mass + Continent	0.10	4	1753	10.4	0.00
Listyear ~ Mass + Continent + Mass * Continent	0.11	5	1752	9.8	0.00
Listyear ~ Mass + Group + Continent	**0.17**	**7**	**1742**	**0.0**	**0.45**
Listyear ~ Mass + Group + Continent + Group * Continent	**0.18**	**8**	**1743**	**0.9**	**0.28**
Range size					
Listyear ~ Range	0.09	3	11909	275.6	0.00
Listyear ~ Range + Group	0.20	14	11744	110.2	0.00
Listyear ~ Range + Group + Range * Group	0.24	25	11678	44.4	0.00
Listyear ~ Range + Continent	0.12	4	11866	232.2	0.00
Listyear ~ Range + Continent + Range * Continent	0.13	5	11849	215.7	0.00
Listyear ~ Range + Group + Continent	0.24	15	11669	35.8	0.00
Listyear ~ Range + Group + Continent + Group * Continent	**0.26**	**22**	**11633**	**0.0**	**1.00**

Notes: Mass is $\log_{10}$ body mass and range is $\log_{10}$ geographic range, with categorical variables of continent (Hawaiian or mainland) and taxonomic group. Sample sizes are 216 and 1513 for mass and range, respectively. *K* is the number of parameters; AICc is the Akaike information criterion corrected for small sample size; ΔAICc is the difference between each model and the best model from the candidate set. Bold text indicates models with ΔAICc <2, representing the most parsimonious models, and are considered to be equally supported by the data. Akaike weights (w_i) represent the strength of the evidence that a certain model is the best model given the data and the set of candidate models.

t_{73} = 5.5; $P < 0.00005$). Finally, it is important to note that Hawaiian birds have extremely limited geographic ranges as compared to mainland birds.

As a whole, species demonstrated decreasing range sizes over listing years, but birds, bivalves, and fish exhibited increases in range size over time. Notably, some of these patterns may be due to the nature of specific actions and locations of the taxa listed. For instance, litigation led to a large number of species being listed in 2012, including eight Gulf Coast mussel species with extensive geographic ranges (Cubbage *et al*. 2017). For birds, part of the trends exhibited are likely attributable to the fact that ~87% of Hawaii's birds were listed between 1967 and 1975, all of which have quite small geographic ranges due to the restrictions of an island's size.

Amphibians were one group that diverged from our predictions in both geographic range and body mass over time. The positive relationships exhibited by amphibians are likely due to several factors. First, recognition that amphibians were experiencing declines globally, and in the US, took almost 20 years, and it was another 8 years before the scientific and conservation community responded (Stuart 2012). The number of peer-reviewed articles that examined amphibian populations and their declines has increased substantially since the 1990s (Simon *et al*. 2004), providing additional data critical for the listing of species by the USFWS. Furthermore, the deviation in trend may have to do with idiosyncrasies associated with amphibian lists, which have been characterized by lengthy delays: in some cases, up to 20 years following determination that protection under ESA was warranted (Walls *et al*. 2017). As a result of a lawsuit brought by two environmental groups against the USFWS, a total of 248 new species were listed between 2012 and 2016 (Walls *et al*. 2017). Almost one-third (9 out of 29) of all amphibian species that have ever received an ESA listing were listed in 2013 and 2014. Even though 20 amphibian species were listed prior to this time, lags in granting species formal protection followed by corrective multi-species listings can conceal or alter the temporal patterns expected under our hypothesized trends by altering the rate of change or slope of the relationship. Although it may be speculative to suggest that all of these amphibian species would have been listed earlier, when examining the specific species listed most recently, the importance of our other parameters becomes apparent. Furthermore, because there has been progress since the creation of the ESA in listing species such as amphibians, invertebrates, and other taxa, the general predictions we made for all taxa may not hold true; that is, with increased attention on some taxa, there have been listing pulses (eg bivalves) or increases (eg amphibians) that can influence the trends.

The primary reason(s) for listing a species under the ESA should reflect vulnerability to extinction. However, the conservation community should be aware of the potential for listing biases and their likely causes (Puckett *et al*. 2016). Unfortunately, discerning factors affecting the species listing process with observational data is challenging, and as such we would like to highlight several caveats.

First, several factors will work to limit the list of threatened or endangered species that are independent of vulnerability and perception. These include determining whether the species exists in the first place (Wilcove and Master 2005), our ability to locate and assess species, and the political process involved in species listings (Lieben 1997). For instance, increased pressure by interest groups during the listing process can substantially slow species listing (Ando 1999), and data deficiencies, insufficient information, or other unexplored intricacies of the ESA petition process (https://ecos.fws.gov/ecp/species-reports) may also influence which species are listed or how long the process takes.

Second, distinguishing human perception from extinction vulnerability is complicated by species traits that positively covary with both processes. For instance, many large-bodied species are known to be vulnerable to extinction (Fritz *et al*. 2009) while also being more detectable under our human perception hypothesis. However, there are alternative patterns of covariation among traits that do offer evidence distinguishing the two hypotheses. For example, species with smaller geographic ranges are more likely to be vulnerable to extinction, yet our data showed that they tended to have later listing times than species with large geographic ranges, possibly due to differences in perception of wide-ranging and restricted-range species.

Third, we acknowledge the imperfect nature of our proxies of human perception. However, there are no agreed upon measures of human perception that can be easily analyzed over the spatiotemporal ranges considered in our analysis. In the context of species listing, human perception has been often discussed but never analyzed; nonetheless, such analyses, however imperfect, should be performed to prompt further research on this topic given the important ramifications for species conservation.

One approach to address these caveats and further test predictions between human perception and vulnerability to extinction would be to evaluate species that were petitioned for listing under the ESA but ultimately were not listed. Over 2000 records exist for species that have been petitioned for listing but did not receive protection as a result of the submission (https://ecos.fws.gov/ecp/species-reports). Some species may have been listed at a later date, while others remain unlisted. As such, this database provides a large sample in which reasons for why a species was not listed could be evaluated independently or in conjunction with listed species. This approach may allow for a more in-depth evaluation of human perception measures and their relationships with vulnerability.

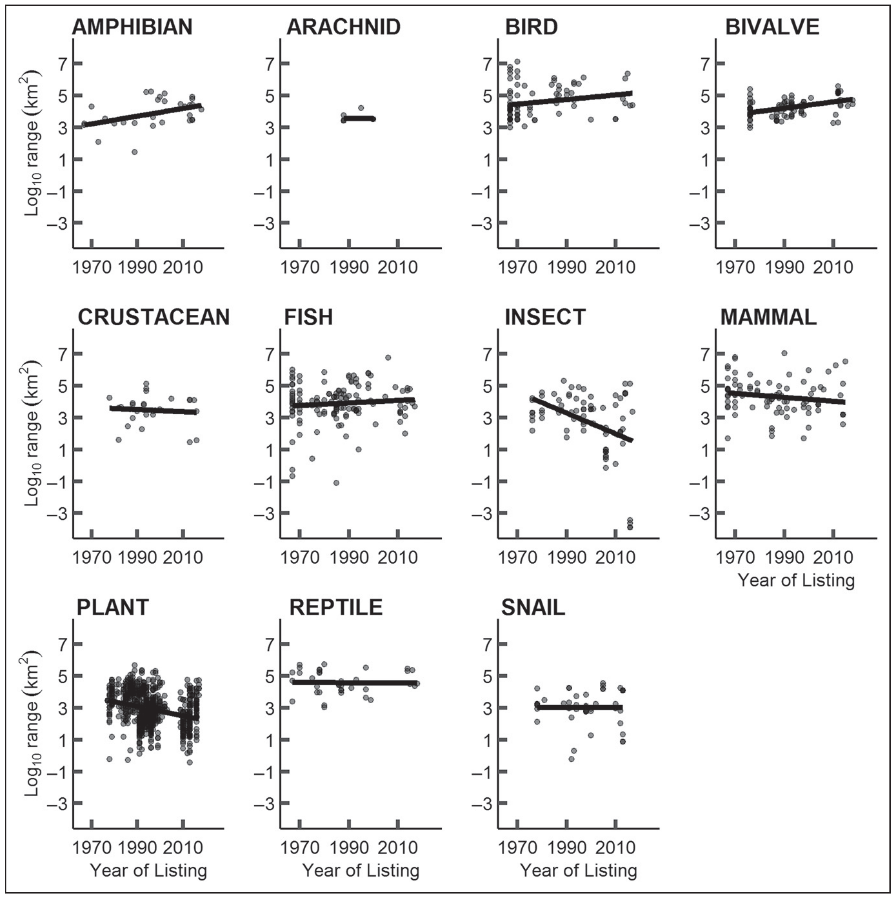

Figure 2. Changes in geographic range (in square kilometers) by listing year for each species within the eleven major taxonomic groups.

Collectively, our findings have important implications for the policy and practice of listing species. Specifically, our findings suggest that we should seek to reduce bias in assessing species for risk of extinction. Reducing bias may require evaluating how current approaches propagate existing biases and account for this with methodological changes. For instance, the USFWS adopted a method to prioritize pending ESA status reviews (USFWS 2016) with petitioned species pending consideration grouped into one of five priority categories ranging from "highest priority" to "limited data currently available". Species classified as "limited data currently available" will be given the lowest priority in this approach and likely reflect the biases we identified in this study. We suggest that the USFWS consider an additional step for species given the lowest priority ranking and determine if the lack of information is likely the result of biases associated with human perception or as a consequence of biological reasons (eg found only in a single location). A species that lacks information due to human perception could be grounds to shift a species from the lowest priority to a higher priority listing with a designation as "new science underway to inform key uncertainties" once this bias has been identified and communicated. Additional measures could be taken by integrating tools into assessments that may have less bias associated with them or be nearly immune from bias. For instance, eDNA has recently been used to survey for rare carnivores, which are often missed by conventional survey approaches (Franklin *et al*. 2019). Likewise, acknowledging known biases is important as agencies and nations create or revise listing processes for threatened and endangered species or at-risk species. Determining which species are at greatest risk of extinction involves assessing uncertainty associated with estimates of current population size and rates of decline. Ultimately, using improved methods and acknowledging current biases will enhance our ability to identify species that may have greater risks associated with them than presently considered.

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Supporting Information

Additional, web-only material may be found in the online version of this article at http://onlinelibrary.wiley.com/doi/10.1002/fee.2574/suppinfo