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The greatest threats to species

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Abstract

The growing human population is responsible for a massive decline in species, biodiversity, and ecosystems across the globe. If we are to significantly slow these losses, the attention and resources devoted to individual causes should be commensurate with the magnitude of their contribution to the problem. The purpose of this study was to determine the relative magnitude of five major threats to species identified by the International Union for Conservation of Nature (IUCN) as threatened with extinction. Specifically, we analyzed the entire IUCN Red List database to determine the percentage of threatened species affected by overexploitation, climate change, pollution, habitat destruction, and invasive species, diseases, and genes. We also randomly sampled a portion of the database to estimate the percentage of species for which each threat was the dominant threat placing them at risk of extinction. Of the 20,784 species for which data were available, 88.3% were impacted by habitat destruction, 26.6% by overexploitation, 25% by invasives, 18.2% by pollution, and 16.8% by climate change and weather. Focusing on dominant threats, the percentage of species for which a given threat was the main factor pushing them toward extinction was as follows: habitat destruction 71.3%, overexploitation 7.4%, invasives 6.8%, pollution 4.7%, climate change, and weather 1.8%. Regardless of how percentages are calculated, habitat destruction threatens more species than all other categories combined, climate change the fewest. From the perspective of species and biodiversity conservation, these data suggest that a significant change in global environmental priorities is needed. Habitat destruction should become a greater focus of global environmental efforts and receive the attention and resources appropriate to the extraordinary magnitude of its impact. Moreover, while it is important to address all environmental problems, given the disproportionate impact habitat destruction has on species, care should be taken to avoid solutions to other problems that exacerbate this destruction.

KEYWORDS

biodiversity, climate change, endangered, habitat destruction, habitat loss, threatened with extinction

1 | INTRODUCTION

The global human population doubled in the past 40 years, reaching just under 8 billion people currently, and is projected to approach 10 billion by mid-century (United Nations, 2019). This rapid explosion of the human population has placed a massive and growing burden on the natural world. Many species across the planet are bearing the brunt of this. Currently, 28% of all assessed species are threatened with extinction, and the number continues to grow (International Union for Conservation of Nature, 2021). In fact, research by Hoffmann et al. (2010) evaluating the impact of conservation measures on threatened birds, mammals, and amphibians found that, on average, species are moving closer to extinction each year. Even if one expands consideration to species that are not currently listed as threatened with extinction, the situation remains bleak. Work by the World Wildlife Fund tracking the size and distribution of nearly 21,000 vertebrate populations over the past half century found populations have declined an extraordinary 68% on average and continue to decrease at an alarming rate (Almond et al., 2020). Similarly, a detailed analysis of 177 mammal species found that every species exhibited range declines of at least 30% and well over a third showed range declines in excess of 80% (Ceballos et al., 2017). The scale of global species declines is so vast that it led Ceballos et al. (2017) to refer to the current situation as an ongoing "biological annihilation."

Such extensive losses do not simply impact the species in question. Loss of species removes genetic and biological resources that could have been utilized by humans for a variety of purposes, including fighting disease and feeding the planet (Almond et al., 2020; Neergheen-Bhujun et al., 2017). Failing to preserve these species will thus undermine sustainable development goals and rob future generations of potentially lifesaving drug discoveries and other human health benefits (Almond et al., 2020; Neergheen-Bhujun et al., 2017; Sandifer et al., 2015). Even when species are not driven extinct across their entire range, the extraordinary number of species undergoing range contractions eliminates large numbers of species from ecosystems they formerly occupied, thereby decreasing the biodiversity of these ecosystems. This can have deleterious impacts on ecosystems, including lower productivity and overall stability (Cardinale et al., 2012; Hooper et al., 2012; Newbold et al., 2016). The negative effects of lower biodiversity are also nonlinear in that declines in ecosystem functions and services accelerate as more species are lost (Cardinale et al., 2012).

Given the importance of species and biodiversity, and the scale of their declines, it is essential that we identify which environmental threats are primarily responsible for the declines and place a greater priority on them. The reason this is needed is human societies have limited time, energy, and resources to address environmental problems. Expending the majority of our effort on solving problems that contribute little to these declines is inefficient and will ensure we ultimately fail to stop the losses. In contrast, expending a greater effort on finding high-yield solutions to the primary drivers of species losses has a much greater probability of solving, or at least reducing, the problem.

What, then, is the greatest threat to the survival of species? While many prominent political figures and international public opinion polls suggest climate change is the greatest threat (BBC, 2015; Dlouhy & Wingrove, 2020; Taylor, 2019; United Nations, 2013, 2018), most studies evaluating the issue directly do not appear to support this (Millennium Ecosystem Assessment, 2005; Venter et al., 2006; Pereira et al., 2012; Maxwell et al., 2016; Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services, 2019). The most comprehensive, recent report on the drivers of species and ecosystem declines comes from the International Science-Policy Platform on Biodiversity and Ecosystem Services (2019). This massive report notes there are myriad individual human activities responsible for biodiversity declines, but notes that land-use change is the single largest contributor to terrestrial and freshwater declines, and overexploitation is implicated as the primary threat in marine ecosystems (Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services, 2019). Another valuable source of data on threats to species is available from the International Union for Conservation of Nature (IUCN) Redlist, which is the most comprehensive global database on the conservation status of all species who have been scientifically assessed (International Union for Conservation of Nature, 2021). More targeted studies examining threats to species have utilized this database, and similarly found that overexploitation and/or habitat destruction rank among the most significant threats (Joppa et al., 2016; Maxwell et al., 2016; Pereira et al., 2012; Venter et al., 2006).

While these latter studies provide important, quantitative assessments of threats to species, they also have limitations. First, each analyzes only select, often well-sampled taxonomic groups. While there are some advantages to this, it is not clear their findings can be extrapolated to threatened species as a whole, or at least all those that have been studied. Second, they did not conduct a separate quantitative analysis of dominant threats. This limits what can be said about which threats are most potent in driving species extinct. The reason for this is that assessors entering individual threats into the Red List often include numerous environmental dangers affecting each species, even when the severity is low or unknown. Some may pose little danger to a given species in isolation, whereas others may constitute the primary factor driving a species toward extinction. Where such disparities exist, it is important to single out the more dominant threats to determine which ones stand out as playing the largest role in pushing the largest fraction of species toward extinction.

The purpose of this study was to build on previous work and obtain a current, comprehensive, quantitative assessment of the greatest threats to species at risk of extinction and to discuss the broader implications of our findings. Specifically, the aim of this study was to (1) examine the entire IUCN Red List database from 2019 to quantify the percent of threatened species affected by each of five major threat categories (climate change, pollution, overexploitation, habitat destruction, and invasive species/diseases/genes); (2) examine a subset of this database to quantify the fraction of species for which each of these five categories constitutes the dominant threat to their existence; and (3) evaluate the public policy and advocacy implications of the results of these two analyses.

2 | METHODS

The IUCN Red List places all species within their database into one of the following categories: Not Evaluated, Data Deficient, Least Concern, Near Threatened, Vulnerable, Endangered, Critically Endangered, Extinct in the Wild, or Extinct. According to the IUCN, species listed as vulnerable, endangered, or critically endangered are considered "threatened with extinction" (International Union for Conservation of Nature, 2019a). These species are the focus of this research.

Data provided by the IUCN on the status and threats to species consist primarily of two spreadsheets: one listing all specific environmental threats faced by each species (hereafter referred to as the "Specific Threats Database"), and another providing a brief description of the main justification for each species' threat category, which typically focuses on the dominant threat(s) responsible for their threatened status (hereafter referred to as the "Dominant Threats Database"). Each spreadsheet served as the basis for a different analysis, each of which is described below.

The Specific Threats Database was used to quantify which major threat category affects the greatest proportion of species at risk of extinction. This database consists of an 81,085 row excel spreadsheet (20,784 species) where each row represents a specific threat a given species is facing. Each specific threat (e.g., residential development, aquaculture, invasive species, etc.) is, in turn, represented by a unique threat code. Threat codes are described in the Conservation Measures Partnership (CMP) Unified Classification of Direct Threats (International Union for Conservation of Nature, 2019b). Following prior convention (Venter et al., 2006), individual threat codes were grouped into one of five major categories: habitat destruction, overexploitation, invasive species/diseases/genes, pollution, and climate change.

Habitat destruction is here broadly defined as the complete loss or significant alteration of a species' habitat by direct human use, such that it threatens the species' existence. This includes conversion of the habitat to other human uses (habitat loss), habitat fragmentation, and direct damage to habitat by human activity within that ecosystem. It excludes indirect damage, such as from pollution, invasive species, climate change, and so forth. CMP threat codes that fall within this definition include all those starting with 1–3 or 6–7, as well as specific codes 4.1–4.3, 5.3.3, 5.3.4, and 5.3.5. Overexploitation is defined as overharvesting of the species being evaluated (through poaching, overfishing, overcollecting, etc.). To qualify as overexploitation, the species itself must be what is harvested, collected, and so forth. Overexploitation is identified within the database by threat codes starting with 5, with the exception of codes 5.3.3–5.3.5. The invasive species, diseases, and genes category is defined as any invasive species, genes, or diseases that are directly or indirectly responsible for placing the species in question at risk of extinction. This category is indicated by CMP codes that start with an 8. Pollution refers to any form of pollution that may be placing a species at risk of extinction (CMP threat codes starting with a 9). Finally, the climate change and weather category consists of any environmental change attributed to climate or weather that is threatening a species' existence (CMP threat codes starting with 11).

The total number of species impacted by each of the five major threat categories was then tallied and divided by the total number of species in the database to obtain the percentage. As most species face multiple threats, a given species may be counted under multiple categories.

It is important to note that the specific threats listed for each species (as well as the dominant threats below) include not only current threats, but also projected future threats. This was particularly relevant for climate change (e.g., anticipated future impact of projected Arctic sea ice declines on polar bear populations). Any attempt to project future risks to a species is fraught with difficulty and varying degrees of uncertainty. This is true of all threat categories, but perhaps none more so than climate change. This may lead some to fear climate change may be under- or over-represented as a threat, depending on the success or failure of the climate models they are based on. While we recognize this is an issue, necessitating caution in interpreting the climate change results, we believe the IUCN "Guidelines for Using the IUCN Red List Categories and Criteria" (International Union for Conservation of Nature, 2019c), section 12.1, does an excellent job of minimizing these concerns.

The Dominant Threats Database was used to determine which of the five major threat categories is the dominant threat to the highest proportion of species. This database consists of a 20,980 row spreadsheet where each species is represented by a single row (International Union for Conservation of Nature, 2019a). One of the columns in this spreadsheet contains the rationale researchers used for listing the species as threatened with extinction. According to the IUCN Threat Classification Scheme (International Union for Conservation of Nature, 2019b), the purpose of the rationale is "To justify the Red List Category and Criteria selected," and should "Include any inferences or uncertainty that relate to the interpretation of the data and information in relation to the criteria and their thresholds." In justifying the Red List category assigned to a given species, and the criteria used for arriving at that designation, assessors typically provide valuable information in the rationale on which threat or threats faced by a given species is/are primarily responsible for its threatened status. Where such information was provided in the rationale, it was used to determine which of the five major threat categories is most responsible for a species being listed as threatened with extinction, as described below.

In order to determine the sample size needed to quantify the percent of species in this database impacted by each dominant threat within a 2% margin of error at a 95% confidence level, we approached the data as a probability-based survey with a known, finite population size (used in most online sample size calculators for surveys). That is, we used the standard equation for calculating the necessary sample size for estimating population proportions in a simple random sample without replacement, corrected for a finite population (Penn State Department of Statistics, 2022): $n = [z^2p(1 - p)/e^2]/[1 + (z^2p(1 - p)/e^2 - 1)/N]$, where n is the sample size needed, z is the z-score for a 95% confidence level (1.96), p is the population proportion (set at a conservative 0.5 to maximize the sample size), e is the desired 2% margin of error (0.02), and N is the sample size of the entire database (20,980). Based on this analysis, it was determined that a sample size of 2155 species would be needed. Thus, 2155 species were randomly selected (without replacement) for analysis. For each species, the rationale was examined and the dominant threat(s) identified. If only one dominant threat was listed, a value of 1 was placed under the appropriate major threat category listed above. For species that had two threats that were clearly dominant, a 0.5 was placed under each of the two categories. If the rationale indicated that there were more than two dominant threats, a 1 was placed in a sixth category called "multiple threats/other." In addition, a small number of species had a dominant threat listed as "geological events." As geological events cannot be clearly identified as human-caused, species fitting this description were also placed under the multiple threats/other category. Finally, for species with rationales that were unclear about the dominant threat(s), the IUCN Red List website (iucnredlist.org) was consulted to determine if the summary on the website contained additional information that could help identify the dominant threat(s). If not, the species was designated as "unclear" and excluded from further analysis. Once 2155 species had been assessed and assigned to a threat category, the total number of species in each category were summed and the percentages calculated.

As the importance of habitat destruction and land use became apparent in these analyses, two additional calculations were performed using the Dominant Threats Database. First, separate calculations were made to discern the percentage of all species examined that were primarily affected by terrestrial versus aquatic habitat destruction. Second, it became clear that a lot of aquatic species are impacted indirectly by terrestrial habitat destruction and use, such as sedimentation from deforestation. In order to determine the fraction of species directly or indirectly impacted by humanity's use of land, all species where the following threats were listed as the dominant or codominant threat were assigned a value of 1 and the percent calculated: terrestrial habitat destruction, aquatic habitat destruction from conversion to land for human use (e.g., agriculture, development, etc.), indirect aquatic habitat damage from pollution resulting from land use (primarily sedimentation from mining, construction, deforestation or agriculture, or nutrient runoff from agriculture), or other indirect aquatic habitat damage from terrestrial ecosystem damage (e.g., loss of shade or altered hydrology from deforestation).

3 | RESULTS

Analysis of the Specific Threats Database revealed habitat destruction was the most common threat, affecting nearly 9 out of every 10 species listed in the database (88.3%; Figure 1). This was more than all the other categories combined. Climate change and weather, by contrast, affected the fewest species (16.8%; Figure 1).

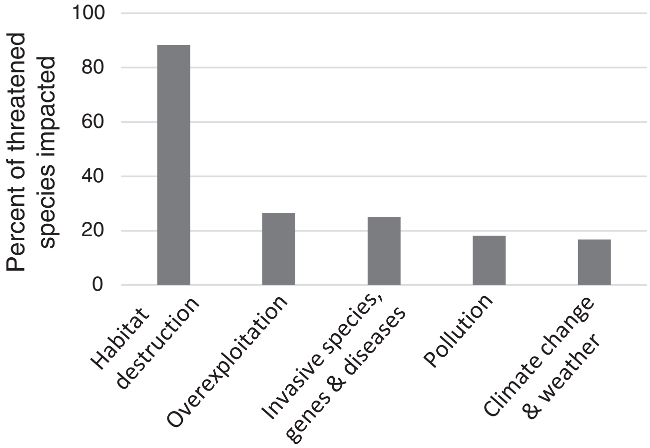

FIGURE 1 Percent of species designated as threatened with extinction that are imperiled by each of five major threat categories (International Union for Conservation of Nature, 2019a). Some species are impacted by multiple major threats and are therefore included in the percentages for more than one category

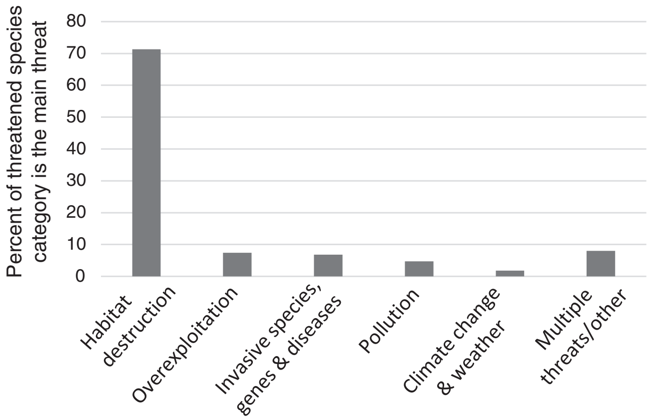

FIGURE 2 Percent of threatened species in which a given major threat category is the primary factor driving the species toward extinction (International Union for Conservation of Nature, 2019a). Species where no clear dominant threats could be identified are listed as multiple threats. Each species is listed only once (or if two dominant threats were identified, the species was assigned half to each category); thus, the sum of percentages from all categories equals 100%

Overexploitation (26.6%), invasives (25.0%), and pollution (18.2%) fell in between (Figure 1).

Results from the Dominant Threat Database revealed a similar pattern, though the differences were considerably more pronounced. Once again, the vast majority of species had habitat destruction as the dominant threat driving them toward extinction (71.3%; Figure 2). This was well beyond the 2% margin of error compared to the next most common danger, overexploitation (7.4%; Figure 2). Similarly, climate change/weather was again the least common dominant threat, affecting only 1.8% of species (Figure 2). This was beyond the 2% margin of error compared to the next highest threat category, pollution (4.7%; Figure 2). Invasives fell in the middle at 6.8% (Figure 2).

Analyzing the category of habitat destruction in greater detail, terrestrial habitat destruction was the dominant threat for the vast majority of species (60.4% of all species examined), with aquatic habitat destruction making up the rest (10.9% of all species examined). When one considers both the direct and indirect impacts of terrestrial habitat destruction and use on species, nearly three-quarters (73.3%) had this as the dominant or codominant threat.

4 | DISCUSSION

These results make clear that the direct destruction and use of habitats (excluding indirect damage from climate change, pollution, etc.) is, by far, the greatest threat to species. In fact, habitat destruction impacts more species than all other threats combined (Figures 1 and 2) and is the dominant threat to an extraordinary 40 times more species than climate change (Figure 2). For the vast majority of species, it is the destruction of terrestrial ecosystems that is the primary problem. While these findings are consistent with most previous studies (e.g., Joppa et al., 2016; Pereira et al., 2012; Venter et al., 2006), by analyzing the full Red List database, and conducting a novel, quantitative analysis of dominant threats, our work not only reinforces previous research, it uniquely highlights the extraordinarily disproportionate extent to which habitat destruction is driving the global biodiversity crisis.

Of course, species should not be the only concern. Species are gathered in communities within a physical environment to form ecosystems. So what does this say for ecosystems? Direct destruction of habitat *is* ecosystem destruction. As of 2000, over half of Earth's ice-free land had been converted to human-dominated landscapes (Ellis et al., 2010; Hooke et al., 2012). Roughly two-thirds of a majority of terrestrial biomes are projected to be converted to human use by mid-century (Millennium Ecosystem Assessment, 2005). Likewise, we have lost more than half of global wetlands (54%–57%) over the past several centuries and the rate of loss has increased dramatically since 1900 (Davidson, 2014; Dixon et al., 2016). Damage to aquatic ecosystems is more complex to quantify but similarly expansive (Dudgeon et al., 2006; Halpern et al., 2015; Luypaert et al., 2020; Pandolfi et al., 2003; Reid et al., 2019; Watling & Norse, 1998). While some habitat destruction is also driven by indirect factors (e.g., climate warming leading to a loss of alpine habitat), the majority of past and present ecosystem destruction, at least on land, is due to direct drivers such as conversion of terrestrial ecosystems to food and fiber production (Millennium Ecosystem Assessment, 2005; Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services, 2019). In fact, the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services found that "land-use change has had the largest relative negative impact on nature since 1970" for both freshwater and terrestrial ecosystems (Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services, 2019). Thus, if we substantially reduce the direct destruction of ecosystems globally, particularly terrestrial ecosystems, we will go a long way toward simultaneously stopping the loss of ecosystems and the species they contain. This leads to two important and interrelated observations.

First, from a conservation perspective, a significant reordering of global environmental priorities is urgently needed. As noted previously, if we are to effectively stop the loss of species, biodiversity, and ecosystems, the amount of attention and resources devoted to a given cause should be proportional to the magnitude of its contribution to the problem. Given that direct destruction of habitats is overwhelmingly the primary driver of species declines, it should be at the center of any efforts to slow or stop the declines. It should not be relegated to obscurity in the shadow of a societal preoccupation with climate change. Our failure to adequately prioritize habitat destruction may explain why we have repeatedly failed to achieve biodiversity targets set under the auspices of the Convention on Biological Diversity (Hoffmann et al., 2010; Tittensor et al., 2014), and will likely continue to do so until we change our priorities.

Going forward, this means habitat destruction should be pushed to the forefront in global conservation discussions. It means that individuals, industries, and policy makers need to place a priority on identifying ways to reduce our land footprint and other direct damage to terrestrial and aquatic ecosystems. Where possible, tractable solutions that have the potential to yield large reductions in our land footprint, and overall rates of habitat destruction, should be sought in all aspects of society. Given that the majority of global habitat destruction is due to food production (Erb et al., 2017; Hogue, 2020; Laurance, 2010), many of the solutions will need to come from this sector of the economy. This includes supporting advancements that simultaneously increase crop yields while minimizing adverse environmental impacts. It should also include re-evaluating support for low-yield methods of crop production, including some organic (Kravchenko et al., 2017; Seufert et al., 2012; Tuomisto et al., 2012). Most importantly, it requires a concerted effort to substantially decrease the consumption of meat and other animal products on a global scale. The vast majority of humanity's land footprint, and much of our contribution to other environmental problems, is for meat and related animal production (Hogue, 2020; Steinfeld et al., 2006). As only a small fraction of this land would be needed to produce the same amount of protein from plant-based sources like soy (Alexander et al., 2017; Eshel et al., 2014, 2016), replacing animal protein in diets with protein-rich plant products has the potential to eliminate the majority of our habitat-destroying land footprint (Hogue, 2020). Since the demand for meat is also a major contributor to overexploitation, greenhouse gas emissions, water pollution, and water withdrawal in aquatic ecosystems (Mansfield, 2011; Steinfeld et al., 2006), replacing it with plant-based proteins would also significantly diminish the role of these other factors in driving species toward extinction.

The second observation arising from these findings is that the current societal focus on climate change has led to the perverse situation where solutions to climate change are being advocated that actually exacerbate the greater danger of habitat destruction. This is particularly problematic in the energy sector where many concerned about climate change have pushed for an expansion of energy sources that are significantly more destructive of habitat than alternative sources. Nowhere is this more the case than with biofuels. Per unit of energy generated, conventional biofuels are estimated to require nearly 1000 times more land than nuclear and 86 times more than natural gas (Brook & Bradshaw, 2015). Even if nuclear technology in the future fails to hold up to the land efficiency assumed by the authors of the aforementioned study (Hendrickson, 2016), this dramatic disparity will persist. Brook and Bradshaw (2015) make clear that the land needed for conventional biofuels is also an underestimate because they based land requirement calculations on high-yield tropical biofuels and only included land needed to grow the crops. This leaves out significant amounts of supporting lands needed in all phases of production and processing these crops, not to mention to generate the petroleum used in each of these phases.

One objection that might be raised about these comparisons is that some of the croplands used to produce some biofuels were converted from food-producing land, and therefore do not add to habitat destruction. As the need for more food and cropland continues to grow in order to feed our growing population (Ray et al., 2013), converting food-producing land to biofuels simply means more cropland must be found elsewhere. Unfortunately, significant amounts of global cropland expansion is occurring at the expense of high biodiversity tropical ecosystems (Li et al., 2019), which has disproportionately negative impacts on species and biodiversity (Kehoe et al., 2017). Even if cropland expansion were not required, an important part of the solution to terrestrial habitat destruction is finding ways to reduce the land footprint of human activities. When it comes to energy, we should be seeking low-land footprint options that allow for meeting growing energy demands without expanded habitat destruction. Given the findings of this study, the vastly higher land footprint of most biofuels suggests it is time for conservationists to call for a phasing out these fuels in favor of considerably smaller footprint alternatives. One of the few biofuel sources that shows promise in this regard is microalgae (Groom et al., 2008).

The problem does not stop at biofuels. Hydropower also has a considerably larger land footprint than nuclear and natural gas (Brook & Bradshaw, 2015). Even solar and wind can be more detrimental than conventional fuels, depending on where they are placed. For example, solar photovoltaic panels or wind turbines placed over potential habitat require roughly 57 and 460 times more land than nuclear, respectively (Brook & Bradshaw, 2015). However, if solar is placed over existing infrastructure (buildings, parking lots, etc.), or wind placed offshore, their contribution to terrestrial habitat destruction would be exceedingly small, and thus preferable. Of course, one must also examine the impact of offshore wind on marine ecosystems. This is not to say that these are the only options, or that there are no other considerations in choosing among energy sources. The key point here is that, if we wish to stem the tide of looming species extinctions and biodiversity declines, we should not advocate solutions to environmental problems affecting relatively fewer species if they make greater environmental threats like habitat destruction worse. In addressing problems like climate change, we should be promoting solutions that also reduce habitat destruction, or at a minimum, result in no net change in the latter. By doing so, it may be possible to reduce the impacts of both problems simultaneously. Failing to do so could have profoundly negative implications for species and biodiversity (Newbold et al., 2015).

In conclusion, if we wish to stop the massive and rapid loss of species and biodiversity across the planet, the findings of this study suggest a significant reorganization of global environmental priorities is needed. Habitat destruction can no longer lie in the shadows of climate change. The former must be pushed to the forefront of global environmental concerns. We must place a priority on finding ways to significantly reduce our land footprint and other contributions to habitat destruction. Where possible, we should seek solutions that have the potential to yield the greatest reductions in habitat destruction and/or reduce multiple categories of threat simultaneously. Just as importantly, when seeking solutions to any environmental problem, we must be mindful of the relative magnitude of major threat categories, and avoid pushing for solutions to environmental problems affecting fewer species that exacerbate problems affecting far greater numbers of species.

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CONFLICT OF INTEREST

To the best our knowledge, neither author has any conflict of interest regarding this research.

AUTHOR CONTRIBUTIONS

Both authors qualify for authorship according to the listed criteria in the order listed.

ETHICS STATEMENT

This entire project is the work of the two listed authors, as described in the manuscript.

DATA AVAILABILITY STATEMENT

The data analyzed in this study were obtained directly from the International Union for the Conservation of Nature (IUCN) Red List of Threatened Species. These data are available at https://www.iucnredlist.org/.

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