CLIMATE CHANGE AND ANIMALS

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Climate change is already having adverse effects on animal life, and those effects are likely to prove devastating in the future. Nonetheless, the relevant harms to animals have yet to become a serious part of the analysis of climate change policy. Even if animals and species are valued solely by reference to human preferences, consideration of animal welfare dramatically increases the argument for aggressive responses to climate change. We estimate that, even under conservative assumptions about valuation, losses to nonhuman life might run into the hundreds of billions of dollars annually. Whatever the precise figure, the general conclusion is clear: an appreciation of the likely loss of animal life leads to a massive increase in the assessment of the overall damage and cost of climate change.

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INTRODUCTION

Polar bears depend heavily on Arctic sea ice for their survival. When sea ice breaks up and drifts as a result of polar warming, the bears must move northward to find stable platforms. Hunting becomes more difficult, because the bears are rarely successful in finding food on open water. Pregnant females, who must leave the ice to find their preferred terrestrial den areas, are forced to swim great distances and to fast for long periods, as the ice drifts farther from land. Even if pregnancy is successful, the bear cubs—raised in suboptimal habitats with malnourished mothers—are most unlikely to flourish.

Harlequin frogs are a vibrantly colorful and active genus of frog in Central and South America. They suffered widespread extinction in the twentieth century—67% of 110 species—despite attempts at habitat protection. The culprit is apparently a pathogenic outbreak triggered by climate change. The chytrid fungus grows on the frogs' moist skin and eats away at their epidermis and teeth, before ultimately killing them. Tellingly, approximately 80% of the lost harlequin species disappeared after an unusually warm preceding year.[1]

The British ring ouzel, a shy species of thrush with a high chirping call, has been in decline for most of the last hundred years. Up to 58% of the population disappeared from 1988 through 1999, and as few as 6000 mating pairs are left. High temperatures and precipitation in the preceding year have been linked to subsequent declines in the ring ouzel population. Biologists speculate that temperature and rainfall extremes have led to a decrease in food availability.[2]

These are but three examples of the potential impact of anthropogenic climate change on animal life and welfare. While the current effects of climate change on human beings are disputed,[3] there is little question that the impact on animal life is already substantial.[4] Projec-

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[1] J. Alan Pounds et al., *Widespread Amphibian Extinctions from Epidemic Disease Driven by Global Warming*, 439 NATURE 161, 163 (2006).

[2] Colin M. Beale et al., *Climate Change May Account for the Decline in British Ring Ouzels* Turdus Torquatus, 75 J. ANIMAL ECOLOGY 826, 827-28 (2006).

[3] Some studies suggest that up to 150,000 human lives are already lost annually due to climate change. *See, e.g.*, Jonathan A. Patz et al., *Impact of Regional Climate Change on Human Health*, 438 NATURE 310, 313 (2005) (citing a World Health Organization study).

[4] *See, e.g.*, Camille Parmesan & Gary Yohe, *A Globally Coherent Fingerprint of Climate Change Impacts Across Natural Systems*, 421 NATURE 37, 41 (2003) (discussing an analysis of over 300 species that shows significant changes caused by climate warming); Terry L. Root et al., *Fingerprints of Global Warming on Wild Animals and Plants*, 421 NATURE 57, 57

tions into the future are much bleaker. One particularly dramatic study, published in *Nature* in 2004, suggests that 15% to 37% of all species—potentially *millions*—could be committed to extinction by 2050 as a result of anthropogenic climate change.[5]

Yet conventional economic analysis of climate change has virtually ignored these effects on nonhuman life.[6] A highly influential study by economists William Nordhaus and Joseph Boyer treats the welfare cost of species loss as too small or uncertain to be accurately quantified.[7] Bjørn Lomborg's well-known analysis of the problem simply fails to discuss animals at all.[8] Nicholas Stern's massive study makes little effort to come to terms with the effects of climate change on animals, notwithstanding its emphasis on the omissions in previous treatments.[9] Richard Tol recognizes the impact of climate change on natural ecosystems, but arbitrarily stipulates a fixed $50 per person willingness to pay to "protect natural habitats" regardless of the anticipated impact.[10]

The consequence of these omissions and stipulations is almost certainly to underestimate, by a large margin, the monetary cost of climate change. Consider the fact that in 2004 alone, federal, state, and local governments in the United States spent over $1.4 billion to protect around 1340 entities (a mere thousandth of the threatened loss from climate change) under the Endangered Species Act (ESA), and expenditures have increased dramatically in recent years as more enti-

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(2003) ("[T]he balance of evidence from . . . studies strongly suggests that a significant impact of global warming is already discernible in animal and plant populations.").

[5] Chris D. Thomas et al., *Extinction Risk from Climate Change*, 427 NATURE 145, 145 (2004).

[6] Climate change will harm all forms of nonhuman life in natural systems. We focus on animals, however, because harm to animals will comprise the lion's share of the social welfare costs stemming from destruction of natural systems.

[7] WILLIAM D. NORDHAUS & JOSEPH BOYER, WARMING THE WORLD: ECONOMIC MODELS OF GLOBAL WARMING 85-87 (2000).

[8] BJØRN LOMBORG, THE SKEPTICAL ENVIRONMENTALIST: MEASURING THE REAL STATE OF THE WORLD 290-300 (2001) (omitting animals from a discussion "of the consequences of global warming").

[9] NICHOLAS STERN, STERN REVIEW: THE ECONOMICS OF CLIMATE CHANGE 169-73, 173-88 (2007). A prepublication version of the *Stern Review* is available at http://www.hm-treasury.gov.uk/indepenent_reviews/stern_review_economics_climate_change/stern_review_report.cfm.

[10] Richard S.J. Tol, *Estimates of the Damage Costs of Climate Change*, 21 ENVT'L. & RESOURCE ECON. 47, 54-55 (2002). Tol himself notes the importance of better analysis in the area. *Id.* at 55.

ties have been added to the endangered list.[11] Moreover, an expenditure measure may well underestimate the true value of endangered species protection, since most of the costs of the ESA are compliance and opportunity costs, stemming from the inability of landowners or governments to engage in otherwise valuable projects. One study estimates that the true annual cost of the ESA (and thus its implied minimum value) is six times greater than nominal government expenditures[12]—implying an annual figure of $8.4 billion for 2004.

A skeptic might try to justify the neglect of animal life in climate change policy analysis in two ways. First, the value of nonhuman life—and the ESA—is heavily debated, and any particular figure will be easy to question. Second, scientific and conceptual uncertainty about climate and natural systems has clouded any attempt at quantification. In 1996, the Intergovernmental Panel on Climate Change (IPCC) wrote:

> Perhaps the category in which losses from climate change could be among the largest, yet where past research has been the most limited, is that of ecosystem impacts. Uncertainties arise both because of the unknown character of ecosystem impacts, and because of the difficulty of assessing these impacts from a socioeconomic point of view and translating them into welfare costs.[13]

In this Article, we contend that neither of these reasons can justify the failure to take account of the effects of climate change on animals. First, animal life matters, both for its own sake and because human beings care about it. As noted above, the United States spends billions of dollars to protect a relatively small number of species under the ESA. Contingent valuation studies consistently show high willingness to pay for the protection of animals. Other recent studies have suggested highly significant instrumental value for biodiversity in areas such as agriculture and medical research. Second, the scientific uncertainty over the impact of climate change on natural systems is rap-

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[11] U.S. FISH & WILDLIFE SERV., FEDERAL AND STATE ENDANGERED AND THREATENED SPECIES EXPENDITURES: FISCAL YEAR 2004, at ii, 1, 7 tbl.c (2006), *available at* http://www.fws.gov/endangered/expenditures/reports/FWS%20Endangered%20Species%202004%20Expenditures%20Report.pdf.

[12] RANDY T. SIMMONS & KIMBERLY FROST, PROP. & ENV'T RESEARCH CTR., ACCOUNTING FOR SPECIES: THE TRUE COSTS OF THE ENDANGERED SPECIES ACT 16 (2004), *available at* http://www.perc.org/pdf/esa_costs.pdf.

[13] INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE [IPCC], WORKING GROUP III, CLIMATE CHANGE 1995: ECONOMIC AND SOCIAL DIMENSIONS OF CLIMATE CHANGE 200 (James P. Bruce et al. eds., 1996) [hereinafter IPCC, ECONOMIC AND SOCIAL DIMENSIONS].

idly diminishing. Many of the most important discoveries have been made only in the past few years, so previous analysts may have been right to assume that scientific knowledge was insufficient to permit precise judgments about damages or causality. But the most extreme claims of causal ambiguity are no longer tenable. While it is an understatement to say that the magnitude of the effects of climate change on animals is still debated, the direction and general significance of those effects are not. Climate change will impose enormous costs on nonhuman life, and ignoring these costs while evaluating climate change policy is no longer excusable.

This Article proceeds in four parts. Part I surveys the recent scientific literature that identifies the potential impact of climate change on animals and other nonhuman life. Part II explores why and how animal welfare might be counted in the evaluation of climate change regulation. Part III offers a partial and highly tentative estimate of the monetized loss from the impact of climate change on nonhuman life. Even under conservative assumptions, focused solely on extinctions and excluding other kinds of animal suffering and death, we estimate that this loss will run into the *hundreds of billions* annually. Despite the tentativeness of the particular number, the unambivalent conclusion is that the prevailing estimates of the costs of climate change must be dramatically increased.

I. SOME EFFECTS OF CLIMATE CHANGE

The fact of anthropogenic climate change is no longer in serious dispute.[14] Carbon dioxide levels in the atmosphere have risen to a level probably unseen in millions of years.[15] Global temperatures have increased by 0.6°C in the twentieth century, and have been projected to increase an additional 1.4°C to 5.8°C for the period from 1990 to 2100. Sea levels rose by 0.10 to 0.20 m in the twentieth century, and are expected to rise an additional 0.09 to 0.88 m in the next hundred

[14] *See, e.g.*, ANDREW E. DESSLER & EDWARD A. PARSON, THE SCIENCE AND POLITICS OF GLOBAL CLIMATE CHANGE 76 (2006) ("We can conclude with high confidence that human greenhouse-gas emissions are the dominant cause of [the] rapid recent warming."); JOHN HOUGHTON, GLOBAL WARMING: THE COMPLETE BRIEFING 9 (3d ed. 2004) (explaining that human activities are causing a warmer climate); IPCC, WORKING GROUP I, CLIMATE CHANGE 2001: THE SCIENTIFIC BASIS 5-9 (J.T. Houghton et al. eds., 2001) [hereinafter IPCC, SCIENTIFIC BASIS] (reviewing the effects of human activities on climate change).

[15] R.T. Pierrehumbert, *Climate Change: A Catastrophe in Slow Motion*, 6 CHI. J. INT'L L. 573, 576 (2006).

years.[16] Extreme weather events may begin to occur with increasing frequency.[17] Perhaps most ominously, some scientists have hypothesized that disruptions to the ocean's thermohaline circulation due to warming of polar waters might perversely trigger an abrupt and massive cooling event.[18]

These climatic shifts are expected to have a series of negative effects on human society. Agriculture will suffer from temperature changes and extreme weather events. Human health will decline, as cases of heat stress increase and diseases such as malaria spread to previously inaccessible regions. Cities such as Venice might be damaged or destroyed by changes in sea level.[19]

There is significant debate, however, about the proper accounting for these potential harms, especially as they pertain to the United States. William Nordhaus and Joseph Boyer, for example, report that the net cost of gradual climate change to the United States, under moderate scenarios, might be "close to zero" because of adaptive responses.[20] Robert Mendelsohn and James Neumann conclude that climate change will create net *benefits* in the United States—largely by boosting agricultural production.[21] In contrast, Samuel Fankhauser and Richard Tol both find that climate change will cause more than $60 billion in annual costs to the United States.[22] Some estimates are much higher.[23] The most recent IPCC panel took a quite different

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[16] IPCC, SCIENTIFIC BASIS, *supra* note 14, at 664, 665 fig.11.9, 671.

[17] STERN, *supra* note 9, at 59, 99-101, 107, 151; David R. Easterling et al., *Climate Extremes: Observations, Modeling, and Impacts*, 289 SCIENCE 2068, 2068 (2000).

[18] R.B. Alley et al., *Abrupt Climate Change*, 299 SCIENCE 2005, 2008 (2003).

[19] NORDHAUS & BOYER, *supra* note 7, at 85; *see also* IPCC, WORKING GROUP I, CLIMATE CHANGE 2007: THE PHYSICIAL SCIENCE BASIS 7 (2007) (predicting a significant rise in the sea level), *available at* http://ipcc-wg1.ucar.edu/wg1/Report/AR4WG1_SPM.pdf.

[20] NORDHAUS & BOYER, *supra* note 7, at 97.

[21] Robert Mendelsohn & James E. Neumann, *Synthesis and Conclusions*, *in* THE IMPACT OF CLIMATE CHANGE ON THE UNITED STATES ECONOMY 315, 321 (Robert Mendelsohn & James E. Neumann eds., 1999); *see also* Olivier Deschênes & Michael Greenstone, *The Economic Impacts of Climate Change: Evidence from Agricultural Profits and Random Fluctuations in Weather* 26 (Mass. Inst. of Tech. Dep't of Econ. Working Paper Series, Working Paper No. 04-26, 2006), *available at* http://ssrn.com/abstract=564722.

[22] SAMUEL FANKHAUSER, VALUING CLIMATE CHANGE: THE ECONOMICS OF THE GREENHOUSE 55 tbl.3.15 (1995); Richard S.J. Tol, *The Damage Costs of Climate Change Toward More Comprehensive Calculations*, 5 ENVT'L. & RESOURCE ECON. 353, 355 tbl.1 (1995); *see also* STERN, *supra* note 9, at 130 (noting that the impact on U.S. GDP may range from a 1.2% loss to a 1% gain).

[23] Claudia Kemfert, *Global Climate Protection: Immediate Action Will Avert High Costs*, 1 DIW WEEKLY REP. 135, 135 (2005) (predicting global damages of $20 trillion by

approach: by shifting its focus from evaluation of costs to mitigation of costs, the panel implicitly assumed that the impact of climate change justified attempts to mitigate its effects *regardless* of the costs.[24]

Notably missing from the debate about the costs of climate change, however, has been an accounting of its potential impact on nonhuman life. As noted above, this is in part due to scientific uncertainty. In 1996, the IPCC emphasized the "unknown character" of potential ecosystem impacts.[25] A string of recent studies, however, has served to reduce this uncertainty.

Consider one finding: a global pattern of "poleward" shifts in habitat range has emerged across ecosystems.[26] As temperatures have increased globally, species have been forced to move to cooler regions; climate change thus acts as a source of human-induced habitat loss. A recent study found that climate change caused an average 6.1 km per-decade poleward shift in range during the twentieth century. The previous per-decade shift would be magnified as a result of the even greater temperature change predicted for the twenty-first century. Of course, if new regions and ecosystems were always perfect and accessible substitutes for a species' old habitat, then there would be no negative impact from such range shifting. (Even if so, many individual animals would suffer and die.) But shifting is generally imperfect: climate change can move faster than species, natural or human-made barriers can prevent shifting, and geographically contiguous habitats are sometimes simply ecologically unsuitable.[27]

Climate change has also caused a chronological shift in "spring events," such as migrant arrival and nesting dates. Such events are occurring earlier in the season: a 2.3 day per-decade shift has been demonstrated in a study of 172 species.[28] As with range shifts, this change need not have a direct negative effect; going to work an hour earlier is not intrinsically harmful. But many species have behavioral patterns, such as migration, that are not linked to seasonal tempera-

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2100); Frank Ackerman & Ian J. Finlayson, *The Economics of Inaction on Climate Change: A Sensitivity Analysis* 16-19 (Global Dev. & Envt'l. Inst., Working Paper No. 06-07, 2006) (concluding that minor changes to assumptions within Nordhaus's DICE model could significantly alter the model's estimated damages from climate change).

[24] *See* LOMBORG, *supra* note 8, at 301.

[25] *See* IPCC, ECONOMIC AND SOCIAL DIMENSIONS, *supra* note 13, at 200.

[26] Parmesan & Yohe, *supra* note 4, at 41.

[27] *See* Thomas et al., *supra* note 4, at 147 (discussing the possibility of climate-related extinction due to the inability of some "species to reach new climatically suitable areas").

[28] *See* Parmesan & Yohe, *supra* note 4, at 38.

ture change. If chronological shifting is either absent or imperfectly linked to temperature, animals will suffer as they attempt to feed, breed, and raise their young in excessively warm or rainy seasonal conditions.[29]

Species that cannot adjust to climate change, either geographically or chronologically, face a number of severe difficulties. Heat is a direct stressor of animal physiology.[30] Rising temperatures affect the availability of vegetation and food necessary for survival.[31] Various biological mechanisms affected by temperature—such as nesting and mating—go haywire under abnormal temperature conditions.[32] Diseases triggered by threshold climate events become more common and deadly.[33] And species must expend more time and energy on thermoregulation when their climatic environment is suboptimal.[34]

Extreme weather events and abrupt climate change also hit animals hard. Even aside from direct storm damage, periods of abnormal precipitation or drought can have adverse behavioral and physiological consequences on species ranging from elephants to turtles.[35] The most recent incident of abrupt climate change stemming from disruption of the ocean's thermohaline circulation system—the Younger Dryas event 10,000 to 11,000 years ago—led to catastrophic ecosystem disruption and mass extinction.[36]

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[29] *See, e.g.*, Christiaan Both & Marcel E. Visser, *Adjustment to Climate Change Is Constrained by Arrival Date in a Long-Distance Migrant Bird*, 411 NATURE 296, 297 (2001) (discussing the negative effects of improper chronological shifting on the population of certain long-distance migrant birds).

[30] *See* William R. Dawson, *Physiological Responses of Animals to Higher Temperatures*, *in* GLOBAL WARMING AND BIOLOGICAL DIVERSITY 158, 158-62 (Robert L. Peters & Thomas E. Lovejoy eds., 1992).

[31] *See* Kevin M. Johnston & Oswald J. Schmitz, *Wildlife and Climate Change: Assessing the Sensitivity of Selected Species to Simulated Doubling of Atmospheric* CO_2, 3 GLOBAL CHANGE BIOLOGY 531, 539 fig.4 (1997) (illustrating that a doubling of atmospheric CO_2 would have significant indirect effects on species distribution within the United States).

[32] *See, e.g.*, M.E. Visser et al., *Warmer Springs Lead to Mistimed Reproduction in Great Tits (*Parus Major*)*, 265 PROC.: BIOLOGICAL SCI. 1867, 1869-70 (1998) (discussing the intensification of "selection for early [egg] laying" in great tits spurred by rising springtime temperatures).

[33] *See* Pounds et al., *supra* note 1, at 161 ("As temperatures rise, climate fluctuations may cross thresholds for certain pathogens, triggering outbreaks. Many diseases are expected to become more lethal, or to spread more readily, as the Earth warms.").

[34] Arthur E. Dunham & Karen L. Overall, *Population Responses to Environmental Change: Life History Variation, Individual-Based Models, and the Population Dynamics of Short-Lived Organisms*, 34 AM. ZOOLOGIST 382, 392-93 (1994).

[35] Easterling et al., *supra* note 17, at 2073.

[36] *See* Alley et al., *supra* note 18, at 2007-08 ("Local extinctions and extensive ecosystem disruptions occurred . . . in fewer than 50 years following the end of the

One study modeled the expected impact of gradual climate change on 1103 species (including mammals, birds, reptiles, and insects) and predicted that a remarkable 15% to 37% would be committed to extinction by 2050.[37] In contrast, over that same period, global habitat loss—the other major source of ecosystem destruction—leads to projected extinction ranges from 1% to 29% in the model, with a figure in the lower end of that range being most plausible.[38] That is, climate change might very well be more destructive to nonhuman life than *all other sources of habitat loss combined*. The lead researcher of the relevant study has stated that "well over a million species could be threatened with extinction as a result of climate change."[39] In comparison, the 1340 entities protected by the ESA are but a drop in the biodiversity bucket.

While such projections are becoming increasingly common, a great deal of scientific uncertainty remains, and the concrete estimates detailed above have been subject to many criticisms.[40] The models used to make climate change impact projections, like all models, are simplifications of the real world.[41] The fact of causation is not seriously disputed, but the precise causal mechanisms for observed and anticipated species loss have been difficult to identify.[42] In addition, the specific regions and species surveyed might not be representative

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Younger Dryas cold event . . . ."); Dorothy Peteet, *Sensitivity and Rapidity of Vegetational Response to Abrupt Climate Change*, 97 PROC. NAT'L ACAD. SCIS. 1359, 1359-60 (2000) (discussing patterns of vegetational change that followed the Younger Dryas event).

[37] Thomas et al., *supra* note 5, at 145. The 15% projection is associated with low climate change scenarios for 2050 (i.e., an 0.8°C-1.7°C increase in global temperature). The 37% projection is associated with high climate change scenarios (i.e., an increase of more than 2.0°C). *Id.* at 147.

[38] *Id.* at 146.

[39] Press Release, Univ. of Leeds, Climate Change Threatens a Million Species with Extinction (Jan. 7, 2004), *available at* http://www.leeds.ac.uk/media/current/extinction.htm (internal quotation marks omitted).

[40] *See, e.g.*, Richard J. Ladle et al., *Dangers of Crying Wolf over Risk of Extinctions*, 428 NATURE 799, 799 (2004) (criticizing media coverage of conservation research for its damaging oversimplification of the scientific findings).

[41] An alternative and recently released extinction study takes a different approach than the Thomas study, using expected loss of vegetation as a proxy for extinction. Jay R. Malcolm et al., *Global Warming and Extinctions of Endemic Species from Biodiversity Hotspots*, 20 CONSERVATION BIOLOGY 538, 539-50 (2006). The reported extinction range is less than 1% to 43%. *Id.* at 542. We focus on the Thomas figures because the Malcolm study is likely to underreport extinctions, since it analyzes biodiversity effects only when a vegetation class changes.

[42] *See* J. Alan Pounds & Robert Puschendorf, *Clouded Futures*, 427 NATURE 107, 108 (2004) ("[F]ew studies have examined how climatic changes might be linked to the immediate causes of [species decline].").

of the global pattern of risk. Finally, as in previous periods of catastrophic ecosystem disruption, new species will eventually move in to replace the old,[43] and some animals are even predicted to benefit from climate change.[44] It is indisputable, however, that many animals will not be so lucky. Like human beings, animals will be affected by climate change. But more so than with human beings, the harms to animals are already apparent, scientifically clear, and of first-order significance.

The question that remains is how to take account of this harm in policymaking. Some might be inclined to treat it as irrelevant, but that inclination would be extremely difficult to defend in principle. On any plausible view, harm to animals matters, at least to some degree. This judgment is firmly reflected in American law. At the national level, the ESA is complemented by the Animal Welfare Act,[45] which is designed to protect a wide range of animals against suffering and premature death. Every state attempts to accomplish the same goal through anticruelty laws. We now turn to competing understandings of how, exactly, human societies should account for the interests of animals.

II. ACCOUNTING FOR ANIMALS

In sketching the effects of climate change, we have emphasized the loss of species as such. In doing so, we follow the scientific literature. But there are actually two separate interests here. The first is species loss; the second is the suffering and death of individual animals. Both are important, though not for the same reasons, and the

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[43] The rate of new speciation, however, is exceedingly low—a mere three species per year—relative to the anticipated annual losses due to climate change. *See* J. John Sepkoski, Jr., *Rates of Speciation in the Fossil Record*, 353 PHIL. TRANSACTIONS ROYAL SOC'Y. B 315, 315 (1998).

[44] For examples of species that might benefit from climate change, see Johnston & Schmitz, *supra* note 31, at 537-38. Even if some species benefit from climatic warming, current extinction rates—even aside from climate change—far exceed baseline rates of new speciation. Substitution and replacement of animals or species thus will not proceed at a pace that implicates the social costs of climate change within a foreseeable timeframe. *See* EDWARD O. WILSON, BIOPHILIA 122 (1984) ("[T]he current rate [of extinction] is still the greatest in recent geological history. It is also much higher than the rate of production of new species by ongoing evolution, so that the net result is a steep decline in the world's standing diversity."); Stuart L. Pimm et al., *The Future of Biodiversity*, 269 SCIENCE 347, 348-49 (1995) (predicting increasing rates of extinction in the future).

[45] 7 U.S.C. §§ 2131-2156 (2000).

second deserves independent attention. If one thousand polar bears or tigers are condemned to extended periods of distress followed by premature death, their suffering and death would matter even if many polar bears and tigers remain.

To be sure, the loss of a species is generally counted as an independent harm—in part because of the ecological and medicinal functions that species provide, and in part because human beings want the opportunity to be able to see and enjoy biological diversity.[46] As we shall see, human beings are willing to pay significant amounts to protect endangered species. But our broader interest here is in harms done to individual animals. Compare, for example, the loss of the last five harlequin frogs with the loss of one thousand polar bears. In our view, the latter loss is far worse, because it involves so much more in the way of suffering and death. More generally, we believe that much of social policy has been unduly focused on extinction, to the neglect of the effects on individual animals. From the moral point of view, threats to both endangered and nonendangered species should matter to climate change policy.

A. *Intrinsic and Instrumental Value*

The most straightforward reason to account for animals is that their interests are intrinsically important. A version of this view was held by Jeremy Bentham, who compared disregard for animal welfare to slavery. In 1789, the year of the ratification of America's Bill of Rights, Bentham argued:

> The day *may* come, when the rest of the animal creation may acquire those rights which never could have been withholden from them but by the hand of tyranny. The French have already discovered that the blackness of the skin is no reason why a human being should be abandoned without redress to the caprice of a tormentor . . . . [A] full-grown horse or dog is beyond comparison a more rational, as well as a more conversable animal, than an infant of a day, or a week, or even a month, old. But suppose the case were otherwise, what would it avail? the question is not, Can they *reason*? nor, Can they talk? but, Can they suffer?[47]

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[46] *See* Gardner M. Brown Jr. & Jason F. Shogren, *Economics of the Endangered Species Act*, 12 J. ECON. PERSP. 3, 11-13 (1998) (detailing the private and social benefits derived from species protection).

[47] JEREMY BENTHAM, THE PRINCIPLES OF MORALS AND LEGISLATION 311 n.1 (Prometheus Books 1988) (1789).

In Bentham's view, utility is what matters, and because animals are capable of suffering, they deserve to count in the social calculus. Utilitarianism is, of course, highly controversial. Perhaps we should accept a form of welfarism[48] not tied to the contested metric of utility, or instead emphasize capabilities[49] or even rights.[50] We do not mean here to endorse any particular theory of why animal life matters. Whatever the proper account, it is widely agreed that animals should count in the social calculus. On this point, there is an incompletely theorized agreement—an agreement in support of judgments and practices, amidst disagreement or uncertainty about what accounts for them.[51] Millions of Americans treat their dogs and cats as beloved family members whose interests count independently of the interests of human beings. Many more agree that animal suffering should be reduced, even if the reduction promises no clear gain for humans. Call this position the *intrinsic value* approach, because it seeks to protect animal welfare for its own sake, rather than because animals are a tool for the ends of human beings.

Of course, many human practices treat animals as worth little or nothing, or as solely of instrumental value. Consider, for example, the use of animals for food, and in particular the harm imposed on animals by factory farms—where chickens have their beaks seared off, cows and pigs are castrated without anaesthetic, and veal calves are chained down in tiny crates for the duration of their short and miserable lives.[52] In many contexts, animal life is valued only to the extent that human beings benefit from it.

To be sure, social practices cannot dispose of the normative question. Bentham himself believed that the infliction of suffering is a prima facie wrong, not to be justified by its pervasiveness;[53] we agree with him. But many people continue to act as if some, most, or all animal life has largely or solely instrumental value, in a way that would raise questions about the extent of human responsibility for their

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[48] *See* AMARTYA SEN, DEVELOPMENT AS FREEDOM 54-86 (1999).

[49] Martha Nussbaum has applied a capabilities approach to nonhuman animals. MARTHA NUSSBAUM, FRONTIERS OF JUSTICE: DISABILITY, NATIONALITY, SPECIES MEMBERSHIP 346-407 (2006).

[50] *See* GARY L. FRANCIONE, INTRODUCTION TO ANIMAL RIGHTS: YOUR CHILD OR THE DOG? (2000); TOM REGAN, THE CASE FOR ANIMAL RIGHTS (1983).

[51] *See* CASS R. SUNSTEIN, LEGAL REASONING AND POLITICAL CONFLICT 4-7 (1996) (outlining the concept and virtues of "incompletely theorized agreements").

[52] *See* PETER SINGER, ANIMAL LIBERATION 95-157 (2d ed. 1990).

[53] *See supra* note 47 and accompanying text.

deaths and suffering—especially, perhaps, with respect to animals in distant lands. Even this view, however, acknowledges that animals can have value—sometimes significant value—and under the instrumental approach, that value must be included in assessments of social policy.

B. *Monetary Valuation*

Whether animals are to be valued intrinsically or instrumentally, difficult issues remain. In the context of human life and health, American agencies assign monetary values on the basis of private "willingness to pay."[54] For example, the Environmental Protection Agency (EPA) values a human life at about $6.1 million, a figure that comes from real-world markets.[55] Human life has intrinsic as well as instrumental value, and risks to human life can be monetized. In the workplace and for consumer goods, additional safety has a price; market evidence has been investigated to identify that price. The $6.1 million figure, known as the value of a statistical life (VSL), is a product of studies of actual workplace risks, attempting to determine how much workers and others are paid to assume mortality hazards. Suppose that people must be paid $600, on average, to eliminate risks of 1 in 10,000. If so, the VSL would be said to be $6 million. Where market evidence is unavailable, agencies often produce monetary valuations on the basis of contingent valuation surveys, which ask people how much they are willing to pay to eliminate or reduce certain risks. Drawing on market evidence and contingent valuation studies, the EPA has recently valued a case of chronic bronchitis at $260,000, an emergency hospital visit for asthma at $9000, a hospital admission for pneumonia at $13,400, a lost workday at $83, and a specified decrease in vision at $14.[56]

Can similar tools be used to determine the value of a statistical life for animals? No labor markets are available to provide compensating differential studies of mortality risk. A contingent valuation study based on the preferences of animals would be infeasible. Polar bears do not have money, and they cannot tell us how much they care about

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[54] *See* W. KIP VISCUSI, FATAL TRADEOFFS: PUBLIC AND PRIVATE RESPONSIBILITIES FOR RISK 19-21 (1992) (detailing the "willingness to pay" approach and its application to public versus private contexts).

[55] *See* FRANK ACKERMAN & LISA HEINZERLING, PRICELESS: ON KNOWING THE PRICE OF EVERYTHING AND THE VALUE OF NOTHING 61, 75-84 (2004) (discussing the "wage-risk" studies from which the $6.1 million figure was derived).

[56] CASS R. SUNSTEIN, THE COST-BENEFIT STATE: THE FUTURE OF REGULATORY PROTECTION 145 tbl.A-3 (2002).

Arctic sea ice. We might be tempted to apply existing market and contingent valuation studies to animals, valuing them at some fraction of human beings. But if so, an appropriate scaling factor would have to be determined, and any such factor might well seem arbitrary. What weight should a frog's life or health have relative to that of a wolf, eagle, or human being?

An alternative approach is to value animals by reference to human preferences, turned into monetary equivalents. Economists typically make the relevant assessments by inquiring into use and nonuse value—a division that corresponds closely to the distinction between instrumental and intrinsic value. Use value includes, for example, the ecosystem services provided by natural life (e.g., pollination by butterflies and bees), the value of biodiversity for agriculture and medical research, and the recreational value of observing natural wildlife. Nonuse value reflects the pure "existence" value of animals or species (such as the value people place on simply knowing that some polar bears will survive), and the "option" value of knowing that animals, including some members of endangered species, are available for future use. Neither use nor nonuse value need be particularly controversial,[57] even from the perspective of committed opponents of animal rights. If people care about animals and are willing to pay to protect them, then animals should matter in policy regardless of their moral status.

The economic approach to valuation of animals raises many questions. Is the value of animals, or species, adequately captured by human willingness to pay for their protection? Imagine a society in which existence value was effectively zero. We might well reject the moral judgments of the people in that society and refuse to believe that those judgments should be the basis for policy and law. Those inclined to accept this objection might nonetheless agree that, when existence value is positive, it should be included in the overall calculus. But if people's willingness to pay does not reflect the proper valuation of animals, it is not easy to identify the proper response. Perhaps the figures should result from processes of democratic deliberation, not from market evidence. But whatever its source, any monetary valua-

[57] The idea of existence value raises several puzzles. For example, it makes the value of an animal or species depend on the human population size. But plausibly that value, to human beings, does increase with the size of the human population. For a discussion of other concerns about the concept of existence value, see David A. Dana, *Existence Value and Federal Preservation Regulation*, 28 HARV. ENVTL. L. REV. 343, 349-53 (2004).

tion of animals will inevitably be made by human beings. At the very least, we believe that use, existence, and option value, to the extent that they can be elicited, are legitimate parts of the climate change debate, and that they should be incorporated rather than neglected.

Even if this conclusion is accepted, there are severe implementation difficulties in determining the relevant monetary values. As we shall see, serious efforts have been made to generate monetary figures for the use value of species. But when the use value of animals is a public or common good, reliable market mechanisms are unavailable for translation into monetary benefits. For nonuse value, the ordinary instrument consists of contingent valuation studies, and we shall make use of such studies here. But such studies raise many problems and, if not designed carefully, will produce implausible answers. In the climate change context, the possibility of small errors is especially important: when one is talking about millions of species, even miniscule changes in the species- or individual-level analysis will lead to dramatic changes in the estimated social value or cost.

Valuation difficulties of this sort, however, are not reasons for ignoring the relevant costs entirely, particularly when the stakes are large. Just as scientific uncertainty has been reduced over time, so too has the conceptual uncertainty about the accuracy of various methods of nonmarket valuation. If there is a gap in the analysis of climate change and animals, it is a gap in the literature, not in the availability of relevant facts or conceptual tools. Our initial submission is that losses of animal life should play a significant role in the debate. Let us attempt, then, to make some progress on the question of monetization.

III. THE (ANIMAL) COSTS OF CLIMATE CHANGE

We provide here a tentative estimate of some of the social welfare costs of climate change on nonhuman life, focusing on human valuations. Because of empirical and conceptual difficulties, we do not insist on any particular figures.[58] Instead, we offer ranges designed to capture the monetized value of merely one component of social loss: the loss of endangered species. The foregoing discussion should be

[58] Indeed, one of us is generally skeptical of cost-benefit analysis as a decision mechanism in environmental regulation; the other is a defender of considering the outcome of that analysis, without making it decisive. *See generally* CASS R. SUNSTEIN, RISK AND REASON, at ix-x (2002) (arguing that cost-benefit analysis should be used along with other measures to assess the consequences of regulation).

enough to show that this loss cannot possibly capture the full value of harms to animals as a result of climate change. If suffering and death matter, then animals that belong to nonendangered species matter as well, and the resulting losses will not be included in our analysis. But monetization of the loss of species presents the more tractable questions, because we have some information about the number of species at risk and the human valuation of species loss. Our exclusion of animal death and suffering means that our ultimate figures will be far too low.

We have two minimal goals, one substantive and the other methodological. The first is to show that the numbers are high and that they need to be considered in assessing the losses from climate change. The second is to present some of the difficulties—normative, conceptual, and empirical—involved in assigning monetary values to those losses.

A. *Extinctions*

Our analysis focuses, in particular, on the 15%-37% projected extinction rate noted above.[59] Given the importance of this estimate, some discussion of its nature and plausibility is warranted. Quantitative projections of the global impact of climate change are necessarily difficult.[60] This is true even of its impact on economic systems, where data are abundant. But it is even harder for natural systems. The scientific community lacks a clear measure of the number of species,[61] and determining how each will be affected by climate change is thus a herculean task. The approach used in extinction studies in biology focuses on generic species-area relationships (SAR), rather than specific causal mechanisms. The key assumption is that there is a systematic relationship between habitable area and survival. While this method has received some criticism,[62] it is firmly established in the biological field.

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[59] Thomas et al., *supra* note 5, at 145.

[60] *See* Pounds & Puschendorf, *supra* note 42, at 108 (noting that models might not capture key climatic changes).

[61] *See* IUCN SPECIES SURVIVAL COMM'N, 2004 IUCN RED LIST OF THREATENED SPECIES: A GLOBAL SPECIES ASSESSMENT 6-9 (Jonathan E.M. Baillie et al. eds., 2004) (noting "the high degree of uncertainty surrounding" the number of species).

[62] *See, e.g.*, LOMBORG, *supra* note 8, at 254-55 (arguing that SAR analyses overstate the likelihood of extinction); Owen T. Lewis, *Climate Change, Species-Area Curves and the Extinction Crisis*, 361 PHIL. TRANSACTIONS ROYAL SOC'Y B 163, 164-70 (2006) (discussing the complications of applying SAR methods to climate change).

This method can be applied to climate change because global warming has the effect of reducing the habitable area of most species. Using recently released climate change data, Thomas and his coauthors determine "climate envelope[s]"—climatic conditions under which particular species can survive—and predict how changes to these envelopes reduce effective habitat size.[63] These predictions show that while the climatic stress for any particular animal in any particular year is small, the yearly and global accumulation of habitat loss leads to massive long-run consequences. If human beings impose a small stress on the habitat of every animal on the planet, but do so every year over a period of many decades, many of the animals will eventually die off.

There are, however, potential problems with our use of the extinction projections from Thomas and his coauthors, and these should be noted at the outset. First, there is the question of representativeness. The 1103 species examined by Thomas and his coauthors—while an immense, joint scientific endeavor—nonetheless represent a miniscule portion of the total number of species.[64] The 20% of the terrestrial Earth sampled by this study, moreover, might not accurately reflect the other 80%. But in the absence of good reasons to think that generalization is flawed, reliance on these methods remains plausible. If we are to make *some* assumption about the expected losses, it is surely better to use the best available figure—representativeness concerns acknowledged—than no figure at all.[65]

Second, and even more fundamentally, the 15%-37% extinction rate gives us no information about the number or distribution of species, or the total number of animals at risk. This information is vital to a sound analysis, because the absolute number (and characteristics) of creatures is significant, whether intrinsic or instrumental value is emphasized. Human beings are undoubtedly willing to spend more to save some species than to save others, and they are more willing to save large numbers of animals than small numbers. Our own treatment pays no attention to species-specific characteristics (which might bias our findings upwards or downwards), or to the absolute numbers

[63] Thomas et al., *supra* note 5, at 145.

[64] *See* Ladle et al., *supra* note 40, at 799 (noting the limitations of such a small sample size).

[65] A recent study published in *Nature* suggests that global patterns of species richness are highly correlated across taxons, indicating that representativeness concerns may not be very significant. John F. Lamoreux et al., *Global Tests of Biodiversity Concordance and the Importance of Endemism*, 440 NATURE 212, 213 (2006).

of organisms (rather than species). These are, admittedly, serious omissions on both fronts.

More specific information, however, is difficult to come by. Approximately 1.55 million species have been described and counted to date, but many more remain undiscovered.[66] Projections of the total number of species range from five to fifty million,[67] with a recent study suggesting that a lower figure is possible.[68] In terms of taxonomic distribution, vertebrates comprise a comparatively small 57,739 of the 1.55 million known species.[69] The vast majority of species are arthropods[70]—which are a small portion of the Thomas sample (79 of 1103 species, 69 of which are butterfly species).[71] Finally, the absolute number of animals is virtually impossible to estimate; it is difficult to estimate population sizes of species that are not known to exist! To say the least, uncertainty of this sort is important.

A third problem with the 15%-37% figure is that it provides no guidance as to the *timing* of extinctions. If we are speaking about human valuations, losing polar bears tomorrow would presumably be worse than losing them a hundred years from now.[72] But the SAR models do not estimate the date of extinction, only its inevitability. A predicted extinction thus might occur tomorrow, in 2050, or in 2100.

Fortunately, the estimation methods we use below partially account for this chronological uncertainty. (The exception is the "use" value estimate, as we discuss below.) For example, the contingent valuation results on which we rely ask individuals how much they value the prevention of a negative change in a threatened species' population, rather than its immediate extinction. Similarly, the ESA expenditures we use for our "revealed preference" analysis are incurred to

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[66] IUCN SPECIES SURVIVAL COMM'N, *supra* note 61, at 7 tbl.2.1, 8.

[67] Robert M. May, *How Many Species Are There on Earth?*, 241 SCIENCE 1441, 1441 (1988).

[68] Vojtech Novotny et al., *Low Host Specificity of Herbivorous Insects in a Tropical Forest*, 416 NATURE 841, 843 (2002) (revising current estimates to approximately five million).

[69] IUCN SPECIES SURVIVAL COMM'N, *supra* note 61, at 7 tbl.2.1.

[70] *Id.* (stating that invertebrates account for 1.19 million of the 1.55 million total known species).

[71] Thomas et al., *supra* note 5, at 146 tbl.2.

[72] There is a significant debate, however, as to whether discounting is appropriate when it comes to human health and life. Presumably, critics would be equally concerned about discounting with animal life. *See* Lisa Heinzerling, *Discounting Life*, 108 YALE L.J. 1911, 1912 (1999) (arguing that timing is critical to discounting). For a more in-depth discussion, see Symposium, *Intergenerational Equity and Discounting*, 74 U. CHI. L. REV. 1 (Winter 2007).

prevent population losses and risks of extinction in the future. If we conceive of the Thomas extinction rates as probabilistic risks that are imposed *today*, and find monetary measures that reflect risk rather than immediate extinction, then the discounting problem fades in importance. If, for example, people are willing to pay twenty dollars now to reduce a one in ten thousand risk that will come to fruition in twenty years, then the resulting figure can be used without discounting.

Fourth, and as we have emphasized, extinction rates ignore the death and suffering of creatures that do not go extinct. This will serve to bias our estimates downward, and significantly so. Warming of polar waters will have severe consequences for polar bears, even if it does not lead to their extinction. An effort to calculate human use and nonuse value would take account of the relevant losses, to the extent that people cared about polar bear suffering, independent of extinction risk. Global estimates of the suffering caused by climate change, however, are even harder to come by than death estimates.[73] Such estimates would require close observation of every species, which is obviously not possible when most species have not even been identified.

Finally, the SAR models do not fully account for the expected costs of extreme weather events[74] or abrupt climate change. Again, this will serve only to bias our results downward.

The upshot of this discussion is that, while there are significant problems in using the Thomas extinction measure, it remains a useful foundation for our analysis. If we can obtain a monetary value from that measure, it will at least identify a component of the social loss from climate change.

B. *Three Assumptions*

Before proceeding to our estimates, we describe three additional assumptions. First, we rely throughout on a low-end assumption about the total number of species—five million. (This is half the minimum number cited by Lomborg, for example.) This figure provides a con-

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[73] E-mail from Chris D. Thomas, Professor of Conservation Biology, Univ. of York, to Wayne Hsiung (June 2, 2006) (on file with authors).

[74] The Thomas model accounts for differences in mean temperature related to extreme weather events, such as heat waves. It does not, however, account for possible increases in storm activity, year-to-year temperature variance, and other changes in climate extremes. Thomas, et al., *supra* note 5, at 147 (omitting these variables from the explanation of the climate scenario methodology).

servative baseline for evaluating the impact of climate change.[75] The implication is that anywhere from 0.75 to 1.85 million species will be lost under climate change scenarios by 2050.

Second, for calculations that are sensitive to taxonomic distribution, we assume that all vertebrate species have been identified. Under this assumption, the 57,739 figure cited above exhausts the universe of vertebrate species. The alternative assumption is that vertebrates comprise the same proportion of unknown as known species. This approach would increase the estimate of vertebrate species from 57,739 to around 186,000. The real number of vertebrate species is somewhere between these two figures, but probably much closer to the former, as vertebrate species are more likely to be currently identified.[76] In order to avoid speculation in an area in which biologists have little information, we conservatively assume that the 57,739 figure is correct. Relying on the 15%-37% extinction rate, we thus estimate that anywhere from 8700 to 21,400 vertebrates eventually will be lost under climate change scenarios by 2050.[77]

Finally, we assume a linear individual and social value function for species loss in all estimates. If we are valuing animals for their own sake (i.e., intrinsically), then presumably each animal should count for approximately the same amount as the last.[78] On the other hand, the correct value or cost function for instrumental value might be concave or convex, not linear, when it comes to species loss. Concavity would imply diminishing marginal utility for species protection. For example, if we conceive of species protection as a consumption good, we might decide, after spending money to protect polar bears and ring ouzels, that protecting harlequin frogs "just isn't worth as much." Some experimental findings suggest that species protection is

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[75] *See* LOMBORG, *supra* note 8, at 250 (asserting that ten to eighty million species is the current best estimate).

[76] *See* IUCN SPECIES SURVIVAL COMM'N, *supra* note 61, at 8 (calling vertebrates the "best evaluated group").

[77] We assume that the extinction rate for fish will be similar to the extinction rates for other vertebrates. Due to data limitations, Thomas and his coauthors examined only terrestrial vertebrate species; the impact of climate change on fish and other aquatic life, however, is not thought to be fundamentally divergent. *See, e.g.*, Catherine M. O'Reilly et al., *Climate Change Decreases Aquatic Ecosystem Productivity of Lake Tanganyika, Africa*, 424 NATURE 766, 768 (2003) (concluding that climate change has contributed to the lake's diminished productivity); Allison L. Perry et al., *Climate Change and Distribution Shifts in Marine Fishes*, 308 SCIENCE 1912, 1912 (2005) (predicting that climate changes may strongly influence numbers and distribution of fish).

[78] There might be different population sizes across species, of course, but as noted previously, data on population size is hard to come by.

a "warm-glow" good—that individuals will pay a fixed amount, and only that fixed amount, to be part of a "good cause," regardless of the expected consequences.[79] Convexity, in contrast, would imply increasing marginal costs for species loss. If we conceive of species loss as a social harm, losing one species might not harm us much—and might not elicit a high marginal willingness to pay—but losing the millionth species would leave us in a biological wasteland. It is unclear which effect should dominate, but we follow a default assumption of linearity. Ideally, contingent value surveys should be able to capture the curvature of the value or cost function, if any, but no studies to date that we are aware of have engaged in this line of research.

C. *Estimates*

We now proceed to our estimation analysis. We report values in two ways: by 2005 U.S. dollars and by percentage of GDP. The two measures have independent significance. The former assumes that real willingness to pay will remain static in perpetuity. The latter implies that species protection will remain a fixed proportion of GDP—that is, as income grows, willingness to pay will grow proportionately. Our hunch is that species protection, like health and environmental protection more generally, will comprise an increasing portion of GDP, both because species protection is likely to be a "luxury good" (i.e., we will spend proportionately more on it as our wealth increases), and because species protection becomes more valuable as more species go extinct. If that is true, then both of our reporting methods will underestimate true social costs.

1. Use Value Estimates

Ecosystems provide immense value for human use. The air we breathe, the soil we farm, the plants we harvest, and the water we drink all depend on ecosystem services. A significant portion of this value is generated by biological sources.

Two recent studies have estimated the value of natural systems for human use. First, a 1997 study published in *Nature* estimated the total (and largely nonmarket) annual value of ecosystem services to be around $33 trillion—around twice the value of global GDP at the

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[79] Tol, *supra* note 10, at 54-55.

time.[80] Not all of this is generated by biological sources, but the aggregate value is broken down by categories, such as food production, gas and climate regulation, water supply, and raw materials.

Previous studies of climate change have accounted for at least some of this value. For example, virtually every study of climate change has examined its impact on food production. The categories relating to natural biological processes, however, have been ignored in climate change analysis. At least four of these categories—pollination, biological control, habitat/refugia, and genetic resources—are comprised entirely of natural biological sources.

Table 1: Value of Biological Ecosystem Services to the World[81]

Categories	**$US 2005 (in billions)**
Pollination	154
Biological Control	550
Habitat/Refugia	164
Genetic Resources	104
World Total	**973**
U.S. Total	**280**

Summing these four totals, we obtain an annual value of biological services of $973 billion in 2005 dollars for the world. Using the Thomas extinction estimate of 15%-37%, the projected loss from climate change is thus $146 to $360 billion in annual value. Excluding habitat/refugia—which is arguably a "nonuse" value—the summed value is $809 billion in 2005 dollars, and the projected loss range is $121 to $299 billion. If we assume that the United States receives a proportion of this use value equal to its proportion of 2005 global GDP, the projected loss for the United States alone ranges from $42 to $103 billion ($35 to $86 billion if habitat/refugia is excluded) annually, or anywhere from 0.4% to 1.1% of annual U.S. GDP (0.4% to 0.9% if habitat/refugia is excluded).[82]

[80] Robert Costanza et al., *The Value of the World's Ecosystem Services and Natural Capital*, 387 NATURE 253, 259 (1997).

[81] These figures are derived from Costanza et al., *supra* note 80, at 256 tbl.2.

[82] All economic statistics are drawn from the Bureau of Econ. Analysis, National Income and Product Account Tables, *available at* http://www.bea.gov/bea/dn/nipaweb/index.asp (last visited May 1, 2007). The exception is the U.S. share of global GDP, which is taken from the CIA World Factbook. *See* CIA—The World Factbook—United States, https://www.cia.gov/cia/publications/factbook/geos/

This figure underestimates the true use value of nonhuman life because many categories of ecosystem services—such as erosion control, soil formation, and nutrient cycling—are of mixed biological and nonbiological origin.

The second study we use, published in *Bioscience* in 1997, avoids this underinclusion problem by breaking down the value of *all* ecosystem services (including services of mixed biological and nonbiological origin, such as soil formation) to which biological sources contribute. The reported annual value of biodiversity for the United States is $389 billion in 2005 dollars, and $3.5 trillion for the world.[83]

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us.html (last visited May 1, 2007). U.S. GDP percentages are calculated with reference to the year of the study.

[83] Daniel Pimentel et al., *Economic and Environmental Benefits of Biodiversity*, 47 BIOSCIENCE 747, 748 tbl.2 (1997).

Table 2: Value of Biodiversity to the United States and the World[84]

	$US 2005 (in billions)	
Categories	**US**	**World**
Waste Disposal	75.6	927.2
Soil Formation	6.1	30.5
Nitrogen Fixation	9.8	109.8
Bioremediation of Chemicals	27.5	147.6
Crop Breeding (Genetics)	24.4	140.3
Livestock Breeding (Genetics)	24.4	48.8
Biotechnology	3.1	7.3
Biocontrol of Pests (Crops)	14.6	122.0
Biocontrol of Pests (Forests)	6.1	73.2
Host Plant Resistance (Crops)	9.8	97.6
Host Plant Resistance (Forests)	1.0	13.4
Perennial Grains (Potential)	20.7	207.4
Pollination	48.8	244.0
Fishing	35.4	73.2
Hunting	14.6	30.5
Seafood	3.1	100.0
Other Wild Foods	0.6	219.6
Wood Products	9.8	102.5
Ecotourism	22.0	610.0
Pharmaceuticals from Plants	24.4	102.5
Forests Sequestering of CO_2	7.3	164.7
Total	**389.2**	**3572.1**

Here, no exclusion is necessary for our estimate, since *all* of these values are from biological sources. The projected loss from climate change is $58 to $144 billion—or 0.6% to 1.4% of GDP—in annual value for the United States (surprisingly close to the estimate suggested by the Costanza et al. study cited in Table 1), and $539 to $1322 billion for the world. Our estimates are summarized in Table 3.

[84] Table 2 is adapted from *id.*

Table 3: Loss in Annual Biodiversity Use Value for the United States[85]

		World Value ($US 2005, in billions)	**US Value ($US 2005, in billions)**	**US %GDP**
Costanza	Low Climate Change	121	35	0.4
	High Climate Change	299	86	0.9
	Low Climate Change (Including Refugia)	146	42	0.4
	High Climate Change (Including Refugia)	360	103	1.1
Pimentel	Low Climate Change*	539	58	0.6
	High Climate Change*	1322	144	1.4

2. Use Value Objections

Three implicit assumptions of our analysis might be challenged. First, we assume that, in ex ante expectation, threatened species will not systematically differ in use value from nonthreatened species. It might be argued, in contrast, that valuable species tend to be more durable, or more adapted to human society, and thus less susceptible to damage from climate change. It seems rather unlikely that dogs or cats will be among the species extinguished by global warming.

While a full empirical defense of this assumption would require an inquiry beyond the scope of this Article, we believe that our assumption is at least plausible. For one thing, we have no reason to suspect that value has any inherent correlation with durability or survivability. Furthermore, value need not imply adaptation to human society; indeed, many currently endangered species, such as some varieties of salmon and sturgeon, have been overused to the point of threatened status precisely because of their value.

Second, and as noted above, we assume a linear value function. That is, the first generic species lost is no more or less valuable, from an ex ante perspective, than the last. Thus, a 10% loss in species im-

[85] Asterisks indicate best estimate. "Low" and "high" refer to low- and high-end climate change scenarios for 2050. *See supra* notes 3-5 and accompanying text.

plies a 10% loss in biological use value. Some commentary, in contrast, has suggested that the biodiversity use value function is concave because of redundancies in biological resources.[86] The value of biodiversity, under this view, is not heavily affected by the loss of a particular species, so long as there are biologically and genetically similar organisms that are not lost (i.e., the "genetic distance" between lost and surviving species is small). For example, we might not care much about the first 109 species of harlequin frog, if we know that the 110th will survive.

We have three responses to this objection. First, if threats to biologically similar organisms are correlated, as is surely the case, redundancy need not make the value function concave over its entire domain, but rather simply discrete (e.g., a stepwise function that increases or decreases only at certain threshold points). So long as we expect one class of organisms to be no more or less valuable than the next class, the linear approximation will be valid. Second, more recent commentary has challenged the "genetic distance" approach to valuing biodiversity because redundancy serves an insurance-like function against catastrophic loss. For example, if some pathogen attacks harlequin frogs, we will be better off with 110 species than with just one, since the 110th species will be more likely to have some adaptive characteristic that will allow it to survive the threat.[87] More generally, the fact that two species are very similar need not make them redundant in value, if the small differences serve some vital function. Finally, to the extent that species are ecologically interdependent, protection of one species will be required to protect many others.[88] We acknowledge that if our assumption here is wrong, our figure must be diminished accordingly.

A third implicit assumption in our analysis is that no adaptive response is possible when a particular species is threatened. It might be argued, in contrast, that once a valuable species is threatened, human society will act in an ad hoc fashion to prevent its loss. The difficulty with this argument is that damage from climate change, unlike other

[86] For examples, see Brown & Shogren, *supra* note 46, at 11; Stephen Polasky & Andrew R. Solow, *On the Value of a Collection of Species*, 29 J. ENVTL. ECON. & MGMT. 298, 298 (1993); Martin Weitzman, *On Diversity*, 107 Q. J. ECON. 363, 372-73 (1992).

[87] *See* William A. Brock & Anastasios Xepapadeas, *Valuing Biodiversity from an Economic Perspective: A Unified Economic, Ecological, and Genetic Approach*, 93 AM. ECON. REV. 1597, 1601 (2003) (discussing this scenario as applied to plant life).

[88] *See* Pimentel et al., *supra* note 83, at 747 (arguing that the loss of a key species can cause the collapse of an ecosystem).

human-caused environmental damage, is hard to mitigate on a case-by-case basis. The harlequin frogs discussed in the Introduction provide an example of a species for which mitigation strategies have proven futile.[89] Protecting habitat from human intrusion does little good if climate change has already undermined the viability of a creature's habitat, and creating a biosphere or zoo for the world, with controlled environments, is prohibitively costly.

There are three other major sources of error in our estimates. First, we have failed to account for chronological uncertainty about species extinction. This is inevitable since, as noted above, the SAR models provide no guidance about the timing of extinctions. If a species goes extinct in 2100, the loss in use value will be significantly less than if it goes extinct in 2007. Suppose, as seems plausible, that most of the extinctions will occur later rather than earlier. If so, the use of a standard discount rate—say, 3%—will significantly decrease the monetary figures above. On the other hand, the use of the standard discount rate is contested, and it is by no means clear that it is appropriate.[90]

Second, our absolute value estimates ignore the possibility that improved technology will either reduce or amplify the value of biodiversity. Both reduction and amplification are possible. If synthetic substitutes are found, perhaps biodiversity will be less important than it is now. On the other hand, the progress of genetic research may mean that we will find more and more valuable uses for biological resources.[91] The GDP measures simply assume that use value will grow in the same proportion as the other components of GDP, so that a 1% loss today implies a 1% loss in 2050.

Finally, we assume that extinction is the only harm to global biodiversity. In reality, if 90% of a species' population is reduced, this will undermine use value nearly as much as extinction.

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[89] *See* Pounds et al., *supra* note 1, at 161 (noting that harlequin frogs have suffered widespread decline despite habitat protection).

[90] *See, e.g.*, STERN, *supra* note 10, at 49-59 (providing an overview of the discounting problem); Ackerman & Finlayson, *supra* note 23, at 2 (noting debate about the problem and its application); Robert C. Lind, *Analysis for Intergenerational Decisionmaking*, *in* DISCOUNTING AND INTERGENERATIONAL EQUITY 173, 176 (Paul R. Portney & John P. Weyant eds., 1999) (expressing skepticism about the use of the standard discount rate).

[91] *See, e.g.*, Paulo Prada, *Poisonous Tree Frog Could Bring Wealth to Tribe in Brazilian Amazon*, N.Y. TIMES, May 30, 2006, at C1 (reporting ways in which frogs can be especially valuable for biotechnological research).

The first of these three errors suggests overestimation; the second suggests possible overestimation and possible underestimation; the third suggests underestimation. For this reason, we lack confidence in our particular figures. The only unambiguous conclusion is that the costs of climate change will be seriously underestimated if account is not taken of the use value of biological resources.

3. Nonuse Value

We offer two strategies for the estimation of nonuse value. First, we use contingent valuation studies of threatened species to estimate the monetized welfare costs of species loss from climate change. As we shall see, this estimation strategy runs into very serious problems, and one of our goals is to explain those problems. Second, we use expenditures on the ESA as a "revealed preference" measure of species value. Under both strategies, we offer a range of estimates based on differing assumptions about the appropriate valuation method.

a. *Contingent Valuation: Foundations*

Contingent valuation studies directly elicit willingness to pay through surveys that develop a hypothetical market for public goods.[92] Survey participants are given detailed information about the resource in question, as well as the nature of the proposed protection. They are also informed of the consequences of protective inaction—suffering, population loss, extinction, and so forth. In some instances, willingness to pay is determined through open-ended inquiry; in others, respondents are given a discrete set of payment choices, or even a single, referendum-style, yes-or-no choice for a specified dollar amount.

The virtue of the contingent valuation method is that it provides a direct measure of human valuation and avoids the potential circularity of using revealed preferences based on existing regulatory practices. When the question is, "What amount should be spent to protect animals?" it seems most sensible to elicit people's judgments and not to rely on current regulatory expenditures. The current expenditures might very well be too low, because of collective-action problems in political action, or too high, because of interest group pressures. On

[92] For an overview of contingent valuation methodology, see ROBERT CAMERON MITCHELL & RICHARD T. CARSON, USING SURVEYS TO VALUE PUBLIC GOODS: THE CONTINGENT VALUATION METHOD 2-4 (1989).

the other hand, contingent valuation methods might be problematic because of "protest" valuations, framing problems, or other cognitive defects.[93] We shall explore some of these problems in the context of climate change.

Even with these concerns, a well-designed contingent valuation study may turn out to be the best or only available method for measuring nonuse values.[94] In the area of species loss, two major contingent valuation surveys have examined individual willingness to pay. The first, by David Pearce, provides values for ten major threatened species in the United States using seven source studies.[95] Pearce's results are displayed in Table 4.

Table 4: Contingent Value of Species Protection (Pearce)

Species	**Annual value per person ($US 2005)**
Bald Eagle	18.48
Bighorn Sheep	12.81
Blue Whale	13.86
Bottlenose Dolphin	10.43
Emerald Shiner	6.71
Grizzly Bear	27.57
Humpback Whale	65.56
Northern Elephant Seal	12.07
Sea Otter	12.07
Whooping Crane	1.79
Total	**181.33**
Per species	*18.13*
Total (No Humpback)	**115.77**
Per species (No Humpback)	*12.86*

[93] For further discussion of potential problems with the contingent valuation method, see CONTINGENT VALUATION: A CRITICAL ASSESSMENT (Jerry A. Hausman ed., 1993); Peter A. Diamond & Jerry A. Hausman, *Contingent Valuation: Is Some Number Better Than No Number?*, J. ECON. PERSP., Autumn 1994, at 45, 62-63; Daniel Kahneman & Jack L. Knetsch, *Valuing Public Goods: The Purchase of Moral Satisfaction*, 22 J. ENVTL. ECON. & MGMT. 57, 68-69 (1992); Daniel McFadden, *Contingent Valuation and Social Choice*, 76 AM. J. AGRIC. ECON. 689, 706-07 (1994).

[94] DAVID W. PEARCE, ECONOMIC VALUES AND THE NATURAL WORLD 116 (1993).

[95] *Id.* at 74-77.

A more recent study by John Loomis and Douglas White surveyed twenty contingent valuation studies and provided values for seventeen threatened species.[96] In Table 5, where multiple estimates for a species are provided by Loomis and White, we use the average value. We also convert their one-time, lump-sum valuations into annual values (using a 10% discount rate), for the purpose of making apples-to-apples comparisons in our analysis.

Table 5: Contingent Value of Species Protection (Loomis and White)

Species	**Annual value per household ($US 2005)**	**Annual value per person ($US 2005)**
Arctic Grayling/ Cutthroat Trout	2.03	0.79
Atlantic Salmon	10.80	4.20
Bald Eagle	32.40	12.61
Bighorn Sheep	28.35	11.03
Gray Wolf	9.05	3.52
Grey Whale	35.10	13.66
Grizzly Bear	62.10	24.16
Humpback Whale	23.36	9.09
Monk Seal	16.20	6.30
Northern Spotted Owl	94.50	36.77
Pacific Salmon/Steelhead	85.05	33.09
Red-Cockaded Woodpecker	17.55	6.83
Sea Otter	39.15	15.23
Sea Turtle	17.55	6.83
Squawfish	10.80	4.20
Striped Shiner	8.10	3.15
Whooping Crane	47.25	18.39
Total	**539.33**	**209.85**
Per Species	*31.73*	*12.34*

One striking fact about these two surveys is that they imply relatively similar per-species valuations. Dividing the per-household measure from Loomis and White by the average size of a household

[96] John B. Loomis & Douglas S. White, *Economic Benefits of Rare and Endangered Species: Summary and Meta-Analysis*, 18 ECOLOGICAL ECON. 197, 199 (1996).

(2.57 people)[97] leads to a per-species estimate of approximately $12.34 per person annually—compared to the $18 per-person measure from Pearce. Moreover, if the humpback whale outlier is removed from the Pearce survey, as Pearce himself suggests ought to be done,[98] his survey's average drops to $12.86 per person—virtually identical to the $12.34 result found by Loomis and White. While there is some overlap in the contingent valuation source studies surveyed by Pearce and by Loomis and White,[99] the fact that the per-species estimates are similar in magnitude, and not extremely sensitive to the particular species surveyed, is a comforting feature of the data. Contingent valuation methods seem to be arriving at consistent average values.

On the other hand, there are also some troubling irregularities. For example, the whooping crane is valued at $1.79 in Pearce, but an order of magnitude more ($18.39 per person) in Loomis and White. Similarly, the estimated values in both studies exceed the amounts actually expended by respondents on conservation.[100] This fact, however, is consistent with a collective-action problem, and does not necessarily demonstrate an erroneous methodology. Finally, there is a strong possibility of reporting bias: researchers are probably more likely to conduct surveys for high-value than for low-value species. Indeed, two of the twenty-one species surveyed (the steelhead and the red-cockaded woodpecker) are among the ten most costly species in 2004 ESA expenditures.[101]

One final note should be made about this data. The studies surveyed by Pearce and by Loomis and White offered a variety of different population-change scenarios in their queries. For example, many of the surveys were framed in terms of *gain* to an endangered population, rather than avoidance of extinction.[102] In contrast, our analysis assumes that all elicited valuations are tied to extinction. Since valuations for extinction would presumably be higher than valuations for

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[97] Average size of household is taken from the U.S. Census Bureau's 2005 Current Population Survey, *available at* http://www.census.gov/population/socdemo/hh-fam/hh6.pdf.

[98] Pearce, *supra* note 94, at 76 tbl.5.

[99] Three of the seven surveys used by Pearce, *supra* note 94, at 76-77, are also used by Loomis & White, *supra* note 96, at 200 tbl.2.

[100] Pearce, *supra* note 94, at 75.

[101] *See infra* Table 6.

[102] Indeed, it is well established that people attach higher values to losses than to gains, which would affect the results of contingent valuation studies. *See* Daniel Kahneman & Amos Tversky, *Prospect Theory: An Analysis of Decision Under Risk*, 47 ECONOMETRICA 263, 278 (1979).

population loss or gain without extinction, our estimates of the cost of climate change will be biased downward.[103]

b. *Contingent Value: Estimates*

We now proceed to our estimation analysis. We merge the Pearce data with the Loomis and White data, using mean values where species are examined in both studies, to arrive at an annual per-person willingness to pay of $11.84 for a generic species.[104] The obvious way to use this data is to multiply a society's total willingness to pay to protect a species by the expected loss of 0.75 to 1.85 million species. Using population figures from the 2000 census, we find an astronomical range estimate of $2499 trillion to $6164 trillion in annual costs for the United States! Of course, this number should not be trusted. The most obvious reason is that the vast majority of the 0.75 to 1.85 million species anticipated to be lost due to climate change are arthropods (such as insects). In contrast, the contingent value studies generally focus on vertebrates such as mammals and birds. Presumably, most people will value vertebrates more highly than, say, butterflies and beetles.

An alternative estimation method would thus exclude all nonvertebrate species, on the assumption that human beings are not willing to pay anything for them. With that exclusion, the threatened loss is 8700 to 21,400 species. The range estimate drops considerably but is still implausibly high—$29 to $71 trillion in annual costs, or anywhere from three to seven times annual GDP. This number also raises a serious difficulty: would U.S. citizens be willing to pay multiples of their current income to protect *any* number of species?

One likely problem here involves a reporting bias: species examined by contingent valuation surveys might not be representative of species that are not so examined. We adjust our estimate for this possibility in the following way. First, we determine a mean ESA expenditure for the fifteen domestic endangered species in our surveys. We then de-bias our estimate by using ESA expenditures as a baseline. The key assumption underlying this method is that the distribution of ESA expenditures across species roughly captures the distribution of

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[103] Only seventeen of the forty-three total queries were framed in terms of extinction loss. *See* Loomis & White, *supra* note 96, at 200 tbl.2.

[104] We exclude the humpback whale outlier, as suggested by Pearce, *supra* note 94, at 76 tbl.15.

social value. Table 6 provides the resulting species-specific expenditure data.

Table 6: ESA Expenditures on Surveyed Species

Species	**ESA Expenditures ($US 2005, in thousands)**
Atlantic Salmon	7496
Bald Eagle	9837
Bighorn Sheep	714
Blue Whale	67
Gray Wolf	6662
Grizzly Bear	7742
Humpback Whale	666
Monk Seal	2321
Northern Spotted Owl	6980
Pacific Salmon/Steelhead	117,380
Red-Cockaded Woodpecker	14,125
Sea Otter	734
Sea Turtle	28,868
Squawfish	5732
Whooping Crane	1757
Total	**211,081**
Average	*14,072.07*
Total (No Steelhead)	**93,701**
Average (No Steelhead)	*6693*
Average (All Species in ESA)[105]	*592*
Bias factor (No Steelhead)	***11.3***

An obvious outlier in this data is the steelhead, which at $117 million exceeds the next highest species by an order of magnitude. In contrast, the contingent valuation data shows that the steelhead is valued highly—the second highest in our sample—but certainly not as highly as suggested by its ESA expenditures. We thus drop the steelhead from our analysis.

Excluding the steelhead, we calculate a bias multiple of 11.3. That is, the representative species from our sample is approximately 11.3 times more valuable than the mean endangered species. Dividing our estimates of the harm of climate change by this value leads us to a re-

[105] The average here differs from the average ESA cost reported below because we exclude non-species-specific expenditures.

vised cost range from $2.6 to $6.3 trillion in annual value, or anywhere from 27% to 66% of GDP. Our results are summarized in Table 7.

Table 7: Total Contingent Value of Species Loss ($US 2005, in trillions)

	Low Climate Change	**High Climate Change**
Estimated Costs	2499	6164
Estimated Costs (Vertebrates Only)	29	71
Estimated Costs (Vertebrates Only, Adjusted for Reporting Bias)	2.6	6.3
%GDP[106]	27%	66%

Even these adjusted estimates should be taken with many grains of salt. As noted above, contingent valuation methods are plagued by various anomalies. Perhaps most important is what Daniel Kahneman and Jack Knetsch describe as the "embedding effect"—the tendency for elicited valuations to remain relatively similar across surveys, even where theory would predict dramatic differences in willingness to pay.[107] One manifestation of this effect is the insensitivity of valuations to the size of a prospective harm; surveys often elicit similar values from respondents, whether 1, 10, or 100 units of a particular good are the subject of inquiry.[108] If a contingent valuation survey were commissioned to examine popular willingness to pay for 10 species, it might very well obtain values identical to the value we use for a single species. This, of course, would greatly undermine our linear aggregation method. We strongly suspect that an exercise in multiplication, based on existing data, will far exceed people's actual willingness to pay.

For this reason, we do not believe that our estimate accurately captures human valuations, even in a first-best world where collective-action problems are eliminated. To say the least, people are unlikely to devote nearly all of GDP, and much less a multiple of GDP, to the

[106] Calculated relative to a 1995 baseline (the year of the Loomis study) from Bureau of Econ. Analysis, *supra* note 82.

[107] Kahneman & Knetsch, *supra* note 93, at 58-60.

[108] *See, e.g.*, William H. Desvousges et al., *Measuring Natural Resource Damages with Contingent Valuation: Tests of Validity and Reliability*, *in* CONTINGENT VALUATION: A CRITICAL ASSESSMENT, *supra* note 93, at 91, 94 fig.9.

protection of nonhuman life. Opponents of contingent valuation will see our results as confirming evidence for the implausibility of the method; advocates will urge more careful and contextually sensitive inquiries.

We offer a third possibility: instead of interpreting the contingent valuation results as actual willingness to pay, we might instead understand them as suggestive that people are in fact committed to the intrinsic value of nonhuman life—that is, the welfare of animals for their own sake. Surely human society would pay many multiples of GDP to prevent *human* extinction. And some surveys suggest that individual Americans value foreign *human* suffering by an order of magnitude more than what the United States actually expends to alleviate it.[109] The fact that the United States does not spend as much as its people state they would prefer for such causes—whether human or nonhuman—does not necessarily undermine the elicited figure as a normative matter, even if it does undermine it as a descriptive matter.

In short, at this point, our conclusion is lamentably vague: Americans are willing to spend a great deal to protect endangered species—and hence nonuse value, once properly monetized, is quite large.

c. *Revealed Preference*

An alternative and less troublesome strategy for estimating nonuse value is to use data on current ESA expenditures to protect threatened animals. A significant advantage of this data is that it reduces the problem just mentioned; that is, the aggregate figure is alert to a budget constraint, and in that sense it is much more realistic than a figure that emerges from aggregating willingness to pay for each individual species, taken one at a time.

Federal and state government expenditures on the ESA in 2004 were approximately $1.4 billion, and were used to protect 1340 enti-

[109] In a poll of Americans' preferences for the percentage of the federal budget to be expended on foreign aid, Stephen Kull found that the mean response was 14%. In fact, the federal government devotes less than 1% of its budget to aid. PROGRAM ON INT'L POL'Y ATTITUDES, AMERICANS ON FOREIGN AID AND WORLD HUNGER: A STUDY OF U.S. PUBLIC ATTITUDES 8 (2001), *available at* http://65.109.167.118/pipa/pdf/feb01/ForeignAid_Feb01_rpt.pdf. This study must, however, be taken with a grain of salt; it is possible that people would want many uses of the federal budget—education, environmental protection, national defense, basic research—to exceed their current support levels, producing an implausibly high aggregate figure.

ties.[110] ("Entity" and "species" have slightly different meanings in the ESA, but the differences are not significant for the purposes of our analysis.[111]) In contrast, expenditures in 1994 were only $245 million. While part of the reason for this vast jump is the use of a different, and more expansive, measure for expenditures starting in 2001,[112] there is nonetheless a clear and steady trend of increased expenditures over the past decade. The seven-year period from 1994 to 2000 saw an approximate 150% nominal increase; the period from 2002 to 2004 (under the new measure of expenditures) saw an approximate 19% increase. (The year 2001 was an outlier in the general trend, with $2.4 billion in expenditures.[113])

Part of the reason for this expenditure trend is an increase in the number of listed species. In 1994, there were 914 listed organisms; there was thus a 47% increase in listed endangered or threatened species over the examined period. The per-species average, however, has jumped far more than 47%—from $0.27 million per species in 1994 to $1.05 million in 2004, a 290% increase.[114] There are at least two economic explanations for this increase. First, as social wealth increases, demand for species protection will increase, especially if environmental protection is a "luxury" good. Second, as more species go extinct, preservation of a marginal species might be deemed more important. It is also possible, of course, that the increase is simply the result of changing moral commitments or interest group politics.[115]

[110] The operational categories for expenditures at the U.S. Fish and Wildlife Service include fisheries, refuge, land acquisition, law enforcement, research, listing, and consultation, among others. State agencies do not have the same formal categories, but they undertake similar activities. U.S. FISH & WILDLIFE SERV., *supra* note 11, at 3.

[111] "Entity" is a narrower category than "species," so a single species might be represented by multiple entities in the endangered species list. *Id.* at 2. The per-species values we report, therefore, will be *underestimates*.

[112] In particular, nonspecific expenditures were recorded beginning in 2001. *Id.*

[113] *Id.* at 7 tbl.c.

[114] *Id.*

[115] Public choice dynamics, however, could cut in the other direction as well. Widespread but relatively weak preferences generally lead to collective-action problems in the provision of public goods. *See* MANCUR OLSON JR., THE LOGIC OF COLLECTIVE ACTION: PUBLIC GOODS AND THE THEORY OF GROUPS 165-67 (1971) (arguing that large groups of individuals with little to gain are unlikely to act together). If collective-action problems in protecting endangered species are significant, then our revealed-preference measure will significantly underestimate the true value of such protection.

Table 8: Federal and State Expenditures on ESA (Nominal Dollars)[116]

Year	Expenditures (in millions)	Listed Entities	Per Species Average (in millions)
1994	245	914	0.27
1995	298	957	0.31
1996	286	963	0.30
1997	301	1111	0.27
1998	454	1166	0.39
1999	514	1202	0.43
2000	610	1235	0.49
2001	2442	1272	1.92
2002	1192	1285	0.93
2003	1201	1335	0.90
2004	1412	1340	1.05

The expenditure data can be used directly to estimate a social cost for species loss from climate change (note that we are dealing here with the costs to Americans alone, which will bias our estimates downward). Current expenditures on endangered species act as a (minimum) revealed preference for species loss more generally.[117] Following Randy Simmons and Kimberly Frost, we assume that the true cost of the ESA (including compliance and opportunity costs) is sixfold nominal government expenditures, making the 2004 per-species value approximately $6.32 million.[118] This is a conservative multiple; compliance costs in environmental regulation often dominate direct government expenditures by an order of magnitude or more.[119]

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[116] Table 8 is derived from U.S. FISH & WILDLIFE SERV., *supra* note 11, at 7 tbl.C.

[117] *See* Don Coursey, *The Revealed Demand for a Public Good: Evidence from Endangered and Threatened Species*, 6 N.Y.U. ENVTL. L.J. 411, 413-14 (1997) (using public expenditures on endangered species to assess the "'revealed public demand" for each species).

[118] *See* SIMMONS & FROST, *supra* note 12, at 16 (determining that actual expenditures were four times that reported by the government).

[119] The exact multiple is likely to vary significantly on a case-by-case basis; we proceed merely on the assumption that there is a rough correlation between government expenditures and total social costs. It is worth noting, however, that the sixfold multiple is probably very conservative. The Bonneville Power Administration, in California, estimated that its compliance costs (including the opportunity cost of lost power revenues) with regulations governing a single species of salmon were approximately $350 million in 1994 (compared to the mere $245 million in total expenditures reported for all species and government entities in that same year). *Compare* Brown & Shogren, *supra* note 46, at 13, *with* U.S. FISH & WILDLIFE SERV., *supra* note 11, at 7 tbl.C. Similarly, regulations protecting the California coastal gnatcatcher will likely lead to compliance

We first estimate the cost of climate change with no adjustments for taxonomic distribution. The $6.32 million per-species revealed preference from 2004 implies a range estimate of $4.9 to $12.0 trillion annually. A serious criticism of this estimate is that it fails to account for the fact that ESA expenditures are distributed unevenly. The top 100 species account for almost 90% of the government expenditures, and the top 50 account for a little more than 75%.[120] Presumably, opportunity and compliance costs would be similarly proportioned. As long as the taxonomic distribution of species threatened by climate change is the same as the distribution of currently listed endangered species, this should not be a problem. However, this is unlikely to be the case, as arthropods make up the vast majority of existing species but a relatively small portion of the ESA's list, and an even smaller portion of the top 100.[121]

Thus, a more plausible estimate focuses on vertebrate species. In Table 9, we break down expenditures by taxonomy and calculate a value for per-vertebrate loss. Notably, as with the vertebrate analysis using the contingent valuation method, we ignore impacts on nonvertebrate life. This will serve to bias our estimate downward.

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and opportunity costs of up to $5 billion in the period from 2003 to 2020. DAVID L. SUNDING, ECONOMIC IMPACTS OF CRITICAL HABITAT DESIGNATION FOR THE COASTAL CALIFORNIA GNATCATCHER, at ii (2003), *available at* http://www.calresources.org/CRMICHGnatcatcherAnalysis.pdf. Total government expenditures, in contrast, were only around $1.4 million in 2004—suggesting up to a 294:1 ratio of true costs to expenditures. U.S. FISH & WILDLIFE SERV., *supra* note 11, at 7 tbl.C. While the species that have been examined carefully for total social costs are unlikely to be perfectly representative, they are at least suggestive of the likely average ratio.

[120] U.S. FISH & WILDLIFE SERV., *supra* note 11, at 51-54 tbl.2.

[121] It is worth noting, however, that two arthropods do make the ESA top 100 list.

Table 9: ESA Revealed Preference by Taxon

Taxonomy	No. of Species	2004 Expenditures ($US 2004, millions)	2004 % Share	2004 Expenditures (Adjusted)	Per Species Social Cost[122]
Mammals	86	122	0.15	208	14.51
Birds	98	103	0.13	176	10.75
Reptiles	40	42	0.05	72	10.74
Amphibians	19	8	0.01	14	4.31
Fish	142	475	0.60	810	34.22
Total	**384**	**750**	**0.94**	**1280**	**19.98**
Total (No Fish)	**243**	**275**	**0.34**	**470**	**11.58**

Table 9 summarizes per-species values by vertebrate taxon. An obvious outlier is fish, where the annual per-species revealed social value is a whopping $34 million—arguably the result of mixed use and non-use value.[123] One might question why commercial fish interests would lobby for endangered species protection rather than direct subsidies. We nonetheless calculate net social values both including and excluding fish. The results, which are not vastly divergent, are reported in Table 10.

Table 10: Costs of Climate Change to the U.S.: Revealed Preference ($US 2005, in billions; %GDP in parentheses)[124]

	Low Climate Change	High Climate Change
Costs (No Exclusion)	4882 (39.5%)	12,043 (96.9%)
Costs (No Arthropods)	179 (1.4%)	439 (3.5%)
Costs (No Fish)*	104 (0.8%)	255 (2.1%)

[122] 6*x* multiple, $US 2004, in millions.

[123] A representative of the National Marine Fisheries Service offered three explanations for the unusually high expenditures on fish. First, many fish species have significant commercial value. Second, fish species often serve as indicators ("canaries") for the health of aquatic ecosystems. Protecting fish therefore implicitly entails protecting many other aquatic species. Third, fish implicate many diverse sectors of the economy—fisheries, hydropower, and even the timber industry. Email from Marta Nammack, Nat'l Marine Fisheries Serv., to Wayne Hsiung (Sept. 8, 2006) (on file with authors).

[124] Asterisk indicates best estimate.

The estimated cost including fish ranges from $179 to $439 billion annually, or 1.4% to 3.5% of GDP. The estimated range excluding fish, which should be viewed as the best estimate, is $104 to $255 billion, or 0.8% to 2.1% of GDP. Again, since *both* of these estimates exclude all nonvertebrate life, they should be viewed with skepticism. Downwardly biased as they are, the minimum values of these ranges are nonetheless very high—$104 billion is nearly as high as the projected annual abatement costs of the Kyoto Protocol.[125]

D. *Summary and Caveats*

Our best estimate of the total cost of climate change in terms of species loss, including both use and nonuse values, is $162 to $399 billion, or 1.4% to 3.5% of GDP, using the revealed preference method. The range variance is driven by uncertainty in the global temperature projections. Thus, we can move from the high end of these cost estimates to the low end, if climate change is mitigated.[126]

Table 11: Net Costs of Climate Change for the United States ($US 2005, in billions; %GDP in parentheses)

	Low Climate Change	**High Climate Change**
Use	58 (0.6%)	144 (1.4%)
Revealed Preference (RP)	104 (0.8%)	255 (2.1%)
Contingent Value (CV)	2565 (27%)	6310 (66%)
Total (Use + RP)	**162 (1.4%)**	**399 (3.5%)**
Total (Use + CV)	**2623 (27.6%)**	**6454 (67.4%)**

We can now take a fresh look at the costs and benefits of the Kyoto Protocol.[127] While there is significant debate over the effectiveness of

[125] *See* Terry Barker & Paul Ekins, *The Costs of Kyoto for the US Economy*, 25 ENERGY J. 53, 69-70 (2004) (finding that the costs to the United States of the Kyoto Protocol would have been less than 1% of GDP); William D. Nordhaus, *Global Warming Economics*, 294 SCIENCE 1283, 1284 (2001) (estimating that the United States would have incurred annual abatement costs of $125 billion if it had joined the Kyoto Protocol).

[126] An approximately 1.2°C mitigation in expected climate change will move us from the high climate change scenario to the low climate change scenario.

[127] We focus exclusively on the most commonly cited version of the Protocol, which allows permit trading between "Annex I" (largely high income) countries. Kyoto Protocol to the United Nations Framework Convention on Climate Change, Dec. 11, 1997, *available at* http://unfccc.int/resource/docs/convkp/kpeng.pdf.

Kyoto, some estimates anticipate mitigation of approximately 0.15°C by 2100.[128] Nordhaus and Boyer have suggested that mitigation might be as low as 0.03°C, as fossil fuel emissions shift to developing countries. The costs of Kyoto are similarly disputed, but most models suggest annual costs of anywhere from 0% to 4% of GDP, with a value in the lower end of that range (less than 1%) being most plausible.[129] Nordhaus, a treaty skeptic, most recently estimated annual abatement costs of $125 billion for the United States[130]—$186 billion in 2005 dollars—compared to the $18 billion estimated benefit. (For comparative purposes, the U.S. budget for national defense is over $400 billion annually.[131])

If species loss (not animal loss as a whole) is included, the calculus is significantly changed. Using the revealed preference measure of willingness to pay, we estimate that if the Kyoto Protocol reduces warming by 0.15°C, it would buy around $30 billion in annual savings, relative to its worst-case $186 billion annual cost. Even under the most conservative cost-benefit assumptions, the impact of climate change on nonhuman life alone justifies almost one-sixth of the costs of the

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[128] Parry and his coauthors estimate 0.15°C mitigation. The World Energy Council also predicts 0.15°C mitigation. Nordhaus and Boyer, in contrast, suggest 0.13°C in an initial paper, but predict a mere 0.03°C in mitigation in their latest models. *See* Martin Parry et al., *Buenos Aires and Kyoto Targets Do Little To Reduce Climate Change Impacts*, 8 GLOBAL ENVTL. CHANGE 285, 286 (1998) (estimating that the relative warming by 2100 would be 2.54°C if left unmitigated, but would be 2.39°C if mitigated under Kyoto); Michael Jefferson, Deputy Sec'y Gen., World Energy Council, Keynote Address to the 31st Conference of the Japan Atomic Industrial Forum, Inc.: Global Warming and Global Energy After Kyoto, chart 8 (Apr. 20, 1998), *available at* http://www.worldenergy.org/wecgeis/publications/default/archives/speeches/spc980420MJb.asp (graphing the projected effect of Kyoto on global mean temperature and estimating an approximately 0.15°C mitigating effect by 2100); William Nordhaus & Joseph Boyer, *Requiem for Kyoto: An Economic Analysis of the Kyoto Protocol*, ENERGY J. (SPECIAL ISSUE), 93, 104 (1999) (projecting a 0.13°C mitigation); NORDHAUS & BOYER, WARMING THE WORLD, *supra* note 7, at 152 (projecting a 0.03°C mitigation).

[129] For a survey of various models, see Barker & Ekins, *supra* note 125, at 55-70. *See also* LOMBORG, *supra* note 8, at 303 (mentioning the many models of Kyoto that have been developed and how they "generally found much the same picture in relative terms"); Nordhaus, *supra* note 125, at 1283 (noting both the challenges of modeling agreements such as Kyoto and the various models that have been developed, and choosing to apply an updated regional integrated model of climate and the economy in analyzing Kyoto).

[130] *See* Nordhaus, *supra* note 125, at 1284.

[131] OFFICE OF THE UNDER SEC'Y OF DEFENSE (COMPTROLLER), NATIONAL DEFENSE BUDGET ESTIMATES FOR FY 2006, at 5 tbl.1-2 (Apr. 2005), *available at* http://www.dod.mil/comptroller/defbudget/fy2006/fy2006_greenbook.pdf.

Kyoto Protocol for the United States.[132] Because of its low anticipated value for the United States, the Kyoto Protocol nonetheless continues to impose costs in excess of benefits. But it is noteworthy that the cost-benefit calculus is improved significantly by the inclusion of nonhuman life.

The picture for the rest of the world is better. While both our contingent value and revealed preference data are drawn from U.S. sources, we can make a back-of-the-envelope calculation for the rest of the world by using the United States's proportion of global GDP as a scaling factor.[133] The predicted value of the Kyoto Protocol in protecting natural biological systems is $74 billion for the rest of the world, making the total value of the Protocol approximately $78 billion in total.[134] The net value of the treaty for the world, however, is still negative, at –$77 billion annually, given the heavy U.S. costs.

Table 12: Value of the Kyoto Protocol
($US 2005, in billions annually)

US Value (No Animals)	-185
US Savings from Protection of Animals	30
US Total	-155
Rest of World Value (No Animals)	4
Rest of World Savings from Protection of Animals	74
Rest of World Total	78
World Total (Including US)	**-77**

It is worth reiterating that our estimates of the cost of climate change include a number of conservative assumptions. First and most notably, we have ignored any impacts of climate change short of extinction. In reality, both the use and nonuse value of nonhuman life will be dramatically affected by declines in population and suffering independent of extinction. Even species that survive will face habitat loss of up to 85% under high-end climate change scenarios—with

[132] Under the low, 0.03°C mitigation scenario suggested by Nordhaus and Boyer, the Protocol would buy the U.S. $6 billion in annual value.

[133] The key assumption in this calculation is that the rest of the world is willing to spend to protect nonhuman life in proportion to its GDP.

[134] We use Nordhaus and Boyer's 2000 data for our calculations of the benefits value of the Kyoto Protocol to the United States and the world. *See* NORDHAUS & BOYER, *supra* note 7, at 145-68.

population declines of similar magnitude.[135] One could plausibly amplify all of our cost estimates by a substantial figure on this basis. At first glance, an 85% multiplier might be a place to start. To the extent that people place a special premium on the loss of species, however, that figure is likely to be far too high. Nonetheless, an estimate of willingness to pay for the loss of many millions of animals would undoubtedly produce substantial figures. And if human willingness to pay does not adequately capture that loss—as we believe—then such an estimate is itself likely to be far too low.

Second, our reported "best estimates" of nonuse value have neglected nonvertebrate life entirely. This is necessary because of data limitations. Contingent valuation studies tend to examine charismatic mammals and birds rather than insects or plants. The ESA expenditures we use for revealed preference analysis cluster around a similar set of organisms. Nonvertebrates nonetheless account for approximately 5% of total ESA expenditures.[136] It might be reasonable, therefore, to increase our nonuse estimates by that factor.

Third, we have made a number of assumptions that have an unquantifiable but downward impact on cost estimates. For example: We assume a low-end value for the number of species and the number of vertebrates. We ignore the impact of a possible increase in extreme weather events. And we do not even attempt to quantify the risk of catastrophic ecosystem destruction stemming from abrupt climate change. All of these factors will serve to bias our estimates downward.

Fourth, in our evaluation of Kyoto, we ignore the potential learning value of the Protocol in establishing a test case and framework for future international agreements on climate change. Indeed, if we conceive of Kyoto as the first step in a series of progressively steeper greenhouse gas reductions (eventually applying to developing as well as developed countries), evaluating the agreement's costs and benefits on the margin might be inappropriate.[137]

On the other hand, there are some reasons to think that our estimates of the cost of climate change might be biased upward. First, we

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[135] E-mail from Chris D. Thomas, Professor of Conservation Biology, Univ. of York, to Wayne Hsiung (June 22, 2006) (on file with authors).

[136] *See* U.S. FISH & WILDLIFE SERV., *supra* note 11, at 9-49 tbl.1 (tabulating FY 2004 expenditures for all endangered and threatened species).

[137] Nordhaus concedes the learning value of the Protocol. *See* Nordhaus, *supra* note 125, at 1284 (noting that "the major merit of [Kyoto] is that it is the first experiment with market instruments in a truly global environmental agreement," thus making it a potentially "useful if expensive guinea pig").

assume that individuals in the United States value unknown and foreign wildlife as much as they value domestic wildlife. Revealed preference analysis suggests dramatic differences in the value of domestic versus foreign *human* lives.[138] Might the same be true for animals?

Since the U.S. Fish and Wildlife Service has no jurisdiction over foreign wildlife, we cannot compare expenditures for domestic and foreign species in any precise fashion. We offer two reasons, however, to think that the difference between domestic and foreign species value may be smaller than anticipated. First, modern human life is so detached from wildlife that, to the vast majority of individuals, a domestic endangered species is as "foreign" as a nondomestic one. For example, among the top ten most valuable species, as measured by ESA expenditures, are the red-cockaded woodpecker, pallid sturgeon, and right whale.[139] Are such species any less "foreign" than polar bears or giant pandas?[140] Second, if there is a difference, it is not even clear which way the foreign/domestic distinction should cut. Foreign and exotic species (tigers, elephants, etc.) might very well be more prized, precisely because of their rarity on U.S. lands. Indeed, public and private organizations in the United States spend many millions of dollars annually on a handful of foreign giant pandas, possibly making the panda the most valued endangered species, on a per-animal basis, in this country.[141]

A second possible source of upward bias is our failure to discount. As a result of scientific uncertainty in the SAR models, we cannot discount use value with any degree of accuracy. And in our analysis of nonuse value, we assume that there are no significant timing differences between extinction caused by climate change and other sources, such as habitat loss.

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[138] *See* Wojciech Kopszuk et al., *The Limitations of Decentralized World Redistribution: An Optimal Taxation Approach*, 49 EUR. ECON. REV. 1051, 1051 (2005) (estimating, by revealed preference, that some foreign lives, from the point of view of the United States, are valued at as little as 1/2000th the value of domestic lives).

[139] U.S. FISH & WILDLIFE SERV., *supra* note 11, at 6 tbl.B.

[140] To be sure, this would not be true of some forms of use value. However, our use value calculations do not depend on the foreign/domestic distinction, since we are not using a species multiple.

[141] *See* Brenda Goodman, *Eats Shoots, Leaves and Much of Zoos' Budgets*, N.Y. TIMES, Feb. 12, 2006, at A1 (noting that, in addition to expensive upkeep costs, Zoo Atlanta pays a $2 million annual fee to the Chinese government "essentially to rent a pair of giant pandas"); Lynne Warren, *Panda, Inc.*, NAT'L GEOGRAPHIC, July 2006, at 42, 48 (stating that there are eleven pandas in the United States, spread out over four zoos, and that "[h]osting giant pandas costs each zoo an average of 2.6 million dollars a year," a figure that can balloon up to $4 million with the addition of two cubs).

Third, we treat our measures of use and nonuse value as conceptually independent when, in fact, there might be significant overlap—for example, the high ESA expenditures to protect threatened fish.[142] This is not a serious problem for the contingent valuation analysis, since the use value is trivial relative to our calculated nonuse values. However, our central revealed preference estimate would be significantly reduced—up to 50%—by any redundancy in use and nonuse value.

Finally, we should note again that we assume a linear value or cost function for species loss. In reality, there are probably ranges of convexity and concavity. The recent and vast increases in per-species expenditures under the ESA suggest that we are currently in a range of convexity. But at some point well short of 100% of GDP, society would presumably decide to stop paying for species protection, or at least significantly reduce its marginal willingness to pay.[143]

CONCLUSION

Our principal goal in this Article has been to suggest that climate change threatens to kill countless animals, and that their suffering and death should matter to climate change policy. By all estimates, climate change is causing, and will cause, a massive loss of animal life and will produce a great deal of suffering. An adequate accounting of the costs of climate change must consider these effects.

At the same time, we have attempted to explore some of the complexities in assigning monetary values to species and animals. We have distinguished between two overlapping but independent sets of losses: extinction of species and harms done to particular animals. Both of these losses should be included in the overall calculation. Because of limitations in existing data, we have focused only on the loss of species, with the belief that this loss is an important component of the problem.

On the basis of current climate change projections, a plausible and conservative range estimate of lost use values, for the world as a whole, is from $0.5 to $1.3 trillion annually. A plausible and conserva-

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[142] Of course, we exclude fish from our revealed preference analysis. However, it might be the case that commercial interests are important in other instances.

[143] Putting the disputed nature of animal rights aside, this will be true due to income effects. That is, if society were actually spending a significant portion of GDP to protect animals, total social wealth would be reduced. And at reduced wealth levels, demand for all goods and services will decrease.

tive estimate of lost nonuse values, for the world as a whole, is from $0.6 to $1.5 trillion annually. For the United States, the corresponding figures are $58 to $144 billion in lost use value and $104 to $255 billion in lost nonuse value. We have argued, moreover, that these estimates might be downwardly biased because we ignore harms short of extinction, ignore impacts on nonvertebrate life, and fail to account for a possible increase in extreme weather events. On the other hand, our estimates might be upwardly biased because we fail to examine the distributional mix of threatened species (for example, foreign versus domestic), we do not even attempt to discount, and we treat our measures of use and nonuse value as completely nonredundant. Finally, there is a serious and unanswered question about the curvature of the species value function. Our estimates, therefore, are necessarily tentative.

We have nonetheless used our analysis to take a fresh look at the costs and benefits of the Kyoto Protocol. If the Kyoto Protocol reduces warming by 0.15°C, we have estimated that its benefits, for Americans, increase by $30 billion annually, and for the world by $74 billion annually, with the major caveat that these savings might not be sustained without a permanent and long-term solution to climate change. Wider and deeper restrictions on greenhouse gases—for example, those that include developing countries, above all China, a growing contributor—would deliver correspondingly larger benefits.

Our central claim here is that, for too long, the debate over climate change policy has been conducted without paying significant attention to nonhuman life. In our view, animals have intrinsic value, and that value should be included in any judgment about appropriate regulation. But our emphasis has been on existing human valuations, not on abstract claims about the appropriate treatment of species and individual animals. To that extent we bracket some of the most controversial claims about animal welfare. If regulators attend to human valuations of nonhuman life, they will find that existing estimates of the costs of climate change are far too low.