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The Sixth Extinction Crisis Loss of Animal Populations and Species

Gerardo Ceballos, Ph.D.¹, Andrés García, Ph.D.², and Paul R. Ehrlich, Ph.D.³,

¹Instituto de Ecología, Tercer Circuito Exterior S/N, Ciudad Universitaria, Universidad Nacional Autónoma de México, México D. F. 04510, MEXICO. ²Estación de Biología Chamela, Instituto de Biología, Universidad Nacional Autónoma de México. Apartado Postal 21, San Patricio, La Huerta, Jalisco, 48980, MEXICO. ³ Center for Conservation Biology, Department of Biological Sciences, Stanford University, Stanford CA. 94301, USA.

Abstract

Today the number of species is the largest in the history of life; however a considerable proportion of that biodiversity is endangered and many species have suffered anthropogenic extinctions. Species and population extinctions are natural phenomena, and massive biodiversity declines have occurred five times in the remote geological past. However, the current extinction episode, the “sixth extinction wave,” may prove to be the most rapid and devastating. To assess the seriousness of this wave, we analyze the present extent of life’s diversity, the number of species that have gone extinct in historic times, the current rates of species extinction, and the extent of population losses. Estimates of the likely number of eukaryotic species vary from 5 to 100 million, but we are now in a “new age of discovery.” There is an explosion of descriptions of new species even in previously “well-known” groups such as mammals, suggesting that previous estimates of the magnitude of biodiversity may be too low. Based on the 2008 IUCN evaluation of the status of world’s species, we estimate that extinctions caused by human activities are occurring at a rate thousands of times higher than the background rate.

Keywords: biodiversity; new species; sixth extinction crisis; extinction vertebrates; population losses.

I. Introduction

In the last 3.7 billion years, billions of populations and millions of species of diverse life forms have evolved in a dynamic world. Currently, the number of species is thought to be the largest in the history of life; i.e. never before have so many different kinds of organisms coexisted (Sepkoski, 1992; Boero et al., 2004). Over the past few centuries, however, human actions such as habitat destruction, toxic pollutant release, overharvesting, and transport of invasive species have caused a massive decline in biodiversity (Ehrlich and Ehrlich, 1981; Hughes et al., 1997; Vitousek, et al., 1997), and greenhouse gas emissions may make the problem even more acute. The anthropogenic extinctions are now called the “sixth extinction wave,” to connote similarity with five past extinction spasms (Jablonski, 1995; Leakey and Lewin, 1995; Thomas et al., 2004; Novacek, 2007; Wake and Vredenburg, 2008). But this is the first such wave to occur during the existence of *Homo sapiens*, and if it continues unabated it could be a harbinger of the downfall of human civilization and the premature demise of billions of people.

The five previous mass extinction waves have occurred during the Ordovician, Devonian, Permian, Triassic, and Cretaceous geologic periods. These extinction events have some important commonalities: (i) they caused a catastrophic loss of global biodiversity; (ii) they unfolded rapidly (at least in the context of evolutionary and geological time); (iii) their impact was not random taxonomically, because whole groups of species were lost while other related groups remained largely unaffected; and (iv) the survivors were often not previously dominant evolutionary groups (Raup, 1986; Jablonsky, 1986). All four of these features may well characterize the current biodiversity crisis, although this might prove to be one the most rapid since, in terms of geological time, it is occurring in an instant. For several reasons, it is also plausible to think that most recent extinctions remain undetected and that the magnitude of the crisis is larger than usually estimated.

Because of these issues, here we revisit the following questions: 1) How much do we know about the extent of life’s diversity? 2) How many species have gone extinct, and what are the current rates of species extinctions? 3) What is the extent of population losses?

II. The Extent of Life’s Diversity

A major impediment to properly evaluating the magnitude of the current extinction crisis is that we don’t know the number of populations and species on Earth (Ehrlich and Pringle, 2008). Two of the biggest difficulties involve defining both populations and species, especially in the vast world of microorganisms.

Since adopting the current Linnaean classification of living species in 1758, approximately 1.8 to 2 million species have been formally described (Groombridge and Jenkins, 2002; Chapman, 2006; Lawton, 2004). Present estimates of the number of eukaryotic species vary widely. They range from 5 to 30 million (Erwin, 1982; May, 1992; Lawton, 2004; Mace et al. 2005; Chapman, 2006), and may even reach the vicinity of 100 million (Ehrlich and Wilson, 1991). There are, however, still serious informational and definitional gaps that prevent agreement on estimates even to the nearest order of magnitude.

In the 1970s and 1980s, there was a relatively widely accepted idea among environmental scientists that after centuries of exploration, most species of conspicuous groups such as birds and mammals, and to a lesser extent other vertebrate groups, were already described. Scientific and technological advances in the study of biological variation (especially the use of molecular techniques) and the exploration of remote places have revealed large numbers of new species of animals and plants. We are thus in a “new age of discovery”, characterized by the uncovering of previously hidden elements of biodiversity (Donoghue and Alverson, 2000; Ceballos and Ehrlich, 2009). Thousands of new taxa are being described across broad systematic and geographic spectra (Table 1). A recent survey by the International Institute for Species Exploration at Arizona State University indicated that 18,516 previously unknown species were discovered in 2007 – 50 a day and ~1% of all described species (ISSE, 2009; Sogin et al. 2006).

Table 1. Discovery of new species of plants and animals in the last two decades. Examples are from both

remote places such as the Foja Mountains in Papua New Guinea and well studied regions such as the waters off Australia.

Period	Taxonomic groups	Number of Species (% of total)	Region	Reference
1993 – 2005	Mammals	408 (10)	World	Ceballos and Ehrlich (2009)
1992 – 2003	Amphibians	1190 (26)	World	Kohler et al. (2005)
1996 – 2005	Animals/Plants	400	Borneo	Engeler (2006)
2007	Mammals Birds Amphibians Plants	9 1 20 10	Foja Mountains New Guinea	Beehler (2007)
2007	Crustaceans	1200	Pangao Island Philippines	National Geographic (2007)
2007	Mollusks	4000	Pangao Island Phillipines	National Geographic (2007)
2008	Sharks/rays	113	Australia	National Geographic (2008)
2008	Mammals Birds Amphibians Reptiles Fishes Spiders Plants	15 4 91 26 279 88 519	Gran Makong Southeast Asia	WWF (2008)
2009	Mammals Birds Reptiles Amphibians Fish Invertebrates Plants	2 2 16 16 14 60 244	Eastern Himalyas	Thompson (2009)

Of all known species of mammals, 10% (408) have been discovered since 1993 (Ceballos and Ehrlich, 2009). New species not only include small creatures such as rodents and bats, but also “charismatic” species such as monkeys (55 new species), the smallest known deer, a 100 kg bovid, and a living representative of Diatomidae, a family considered extinct for 11 million years. The latter is an example of the “Lazarus effect” (Wignall and Benton, 1999; Dawson et al., 2006), in which a species previously known only from fossils is discovered alive. New mammal species have been discovered practically all over the globe (Figure 1). If subspecies recently elevated to species status are also included, such as clouded leopards and orangutans in Sumatra and Borneo, and forest elephants in central Africa (Roca et al., 2001; Zhang et al., 2001), some 1000 new mammal species have been described in that period.

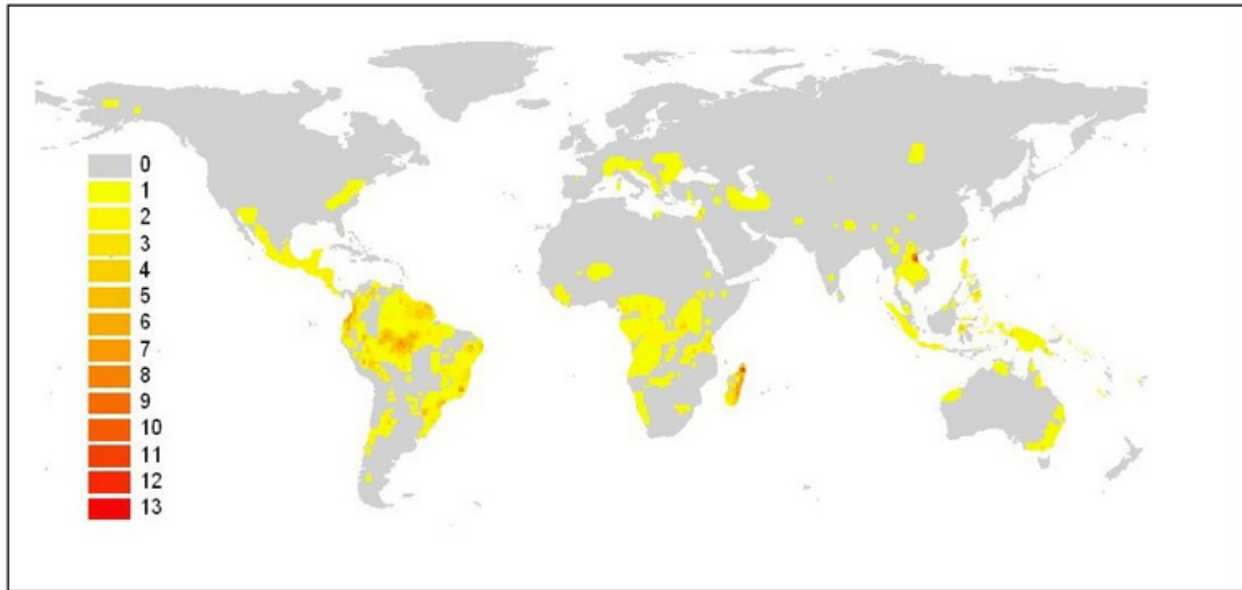


Figure 1. Patterns of distribution of 483 species mammals described since 1993 (Modified from Ceballos and Ehrlich, 2009). The column on the left indicates the number of species in 10,000 km² grid cells.

The number of new amphibians is even more astonishing: 26% of all species were described from 1992 to 2003 (Kohler et al., 2005). Many of the new amphibians discovered were highly divergent, indicating that the newly discovered diversity does not involve what has been called “taxonomic inflation” - the elevation of subspecies to species status or the split of one species into several species (Isacc et al., 2004).

The proportion of unknown species in other less well-studied groups, from insects to fishes, is certainly higher. Such groups also have a much larger number of species than mammals – insect species doubtless number in the many millions, which indicates that we have much more to learn about life on Earth. Clearly, however, the 2 million species already described are a fraction of the total number of species in most animal groups, if a reasonable minimum estimate of extant species is 5 million.

III. Numbers of Extinct Species

There have been many hundreds of anthropogenic extinctions in the last 500 years. Some examples indicate the extent of the extinction problem. In mammals, 76 species such as the Steller sea cow (*Hydrodamalis gigas*, Anderson, 1995) are extinct, 2 extinct in the wild (i.e. surviving only in captivity, SOC hereafter), and 29 possibly extinct (Vie et al., 2009). At least 134 birds, such as the passenger pigeon (*Ectopistes migratorius*) are extinct, 4 are SOC, and are 15 possibly extinct. Amphibians have been severely affected, and 159 such as the golden toad (*Incilius periglenes*) are extinct, one SOC, and 120 species are possibly extinct (Crump et al., 1992; Stuart et al., 2004; Pounds et al., 2008; Vie et al., 2009). In the case of reptiles, 21 species are considered extinct and one SOC, whereas among fishes 91 species are considered extinct and 13 SOC (Vie et al. 2009).

At a regional scale, three examples suffice to indicate the severity of the extinction problem. In Australia, 23 (6%) of mammals have been lost and more than 100 have become endangered in the last 500 years (Morris and Burbidge, 2008; Van Dyke and Strahan, 2008; EPBC, 2009). In the Continental US, 7% (20 of 297) of mussel and clam species and 4% (40 of 950) of freshwater fishes have perished in the past century (Levin and Levin, 2002). In Mexico, roughly 75 species of vertebrates have become extinct in the last two centuries (Ceballos and Márquez-Valdelamar, 2000; Contreras-Balderas et al. 2003).

Thus many hundreds of animal species have already been recorded as lost in the current extinction wave. The

2008 evaluation of the status of 32,765 animals by the International Union of Conservation of Nature (IUCN) recorded 754 “extinctions,” with 717 species listed as extinct and 37 SOC since 1500 (Table 2; Vie et al., 2009). Additionally, it has been documented from sub-fossil remains that more than 2000 birds were driven extinct in prehistoric times in the eastern Pacific islands after human settlement a few thousand years ago (Steadman, 1995).

Table 2. Described and estimated number of animal species either extinct or vulnerable to extinction based on 2008 IUCN report if all species were in the sample. Abbreviations: EX = extinct; SOC = surviving only in captivity; CR = critically endangered; EN = endangered; VU = vulnerable. These categories are the ones used in IUCN to describe different degrees of threat (CR>EN>VU).

	Described Total Number (% evaluated)	Sample in IUCN Report 2008 Ex & SOC	CR, En & Vu	Estimated if all described species would have been evaluated Ex & SOC	CR, En & Vu
VERTEBRATES					
Mammals	5488 (100)	78	1141	78	1141
Birds	9990 (100)	138	1222	138	1222
Reptiles	8734 (16)	22	423	31	840
Amphibians	6347 (99)	39	1905	39	1905
Fishes	30700 (11)	104	1265	104	1275
Subtotal 1	61259 (43)	381	1228	4738	7021
INVERTEBRATES					
Subtotal 2	1232384 (0.50)	373	437	37492	250885
TOTAL	1293643 (2.5)	754	1665	37923	257907

IV. Extinction Rates and Numbers

The lack of a solid estimate of the number of living species is a major obstacle to calculating the number and rate of anthropogenic extinctions in order to compare them to background extinction rates. The IUCN considers that there are 1.8 million described animal and plant species, of which 1.3 million are animals (Vie et al., 2009), on which we will focus from here on. The IUCN evaluated a sample of 32,765 animal species and estimated that 9216 are endangered (28% of the animal species in the sample) including 754 extinct (and a small fraction that SOC) (Table 2).

The estimated background extinction rate (that persisting outside of extinction waves) is one extinction per 100 years per 10,000 species or one extinction per million species years (Pimm and Jenkins, 2009). We recently have addressed the issues of the magnitude of the anthropogenic episode (Ceballos et al., 2010). We calculated that, in

the 30,000 species sample, 15 species extinctions would have been expected for that 500 year period, if there were not an anthropogenic extinction spasm. So the ~750 animal extinctions within the sample indicate an extinction rate over the last 500 years of 50 species per 100 years, per 10,000 species, and thus represent a roughly 50-fold increase over the background extinction rate. But the sample of ~30,000 species is but a tiny proportion of the described number of species.

Assuming that the proportion of extinctions among undescribed species is the same as among the 1.3 million IUCN described animal species, then the number of extinctions would be roughly 6500 species per 100 years, per 10,000 species for all animals. Thus, the estimated rate would represent a several-thousand-fold increase over the background rate of extinctions (Figure 2).

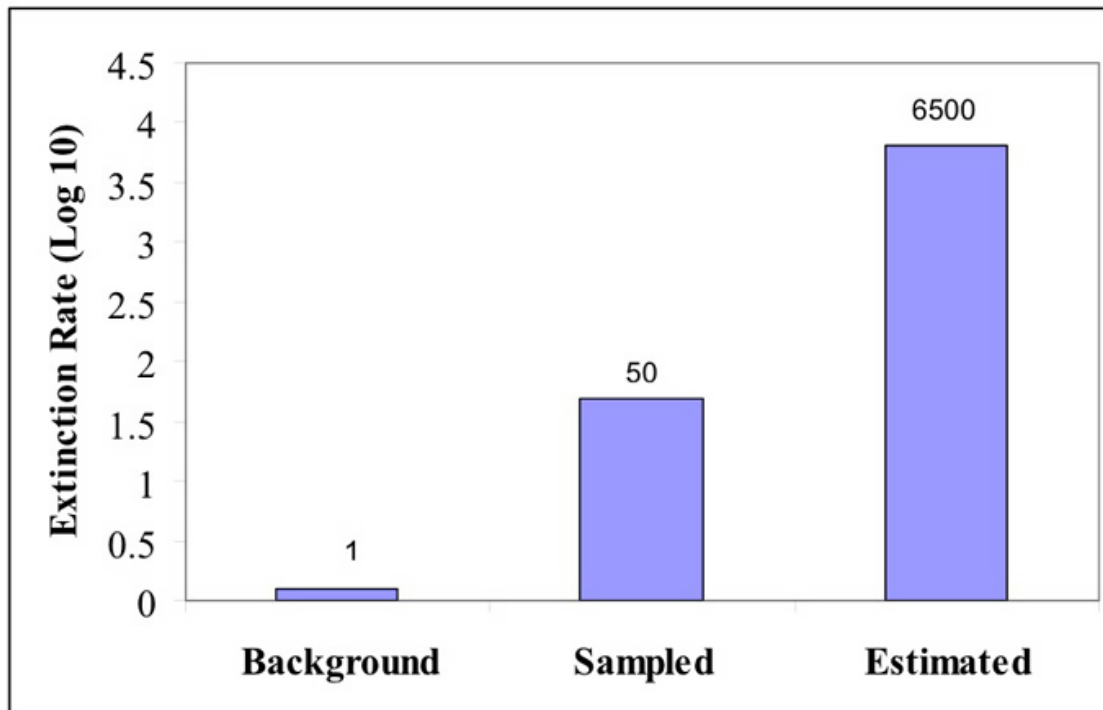


Figure 2. Comparison of background extinction rates (1 species per 100 years, per 10,000 species), and those based on the IUCN 2008 sampled species and the estimated anthropogenic extinction rates (number of species per 100 years per 10,000 species). Note that the anthropogenic rates represent a several-thousand-fold increase over the background rate of extinctions.

These rough but very conservative numbers (excluding plant extinctions and using low estimates of total species diversity) suggest that the current extinction rate is enormously higher than the background extinction rate, indicating the severity of the current extinction spasm (Ceballos et al. 2010).

V. Endangered Species and Population Losses

The ~32,000 animal species whose status has been evaluated by IUCN account for a mere 2.5% of the World's 1,300,000 described animal species (Vie et al., 2009). About a quarter of the evaluated species (~8500) in the IUCN sample were listed as at risk of extinction (see three categories in Table 2). The most accurate estimates are those for vertebrates. Around 30% of all amphibians are endangered, followed by mammals (22%, Figure 3, birds (14%), reptiles (5%), and fishes (4%). If the vertebrate trends are even only a half of the evaluated species across the 1.3 million described animal species, the likely number of animals threatened would be ~260,000 (30 times higher than estimated by the IUCN; Table 2); a high percentage of those threatened species would be invertebrates (97%). Although some claim that extinction rates in invertebrates are lower than in vertebrates, there are already available data supporting the hypothesis that invertebrate extinction rates are similar to those of vertebrates at least

in some groups, such as butterflies (Thomas et al. 2004).

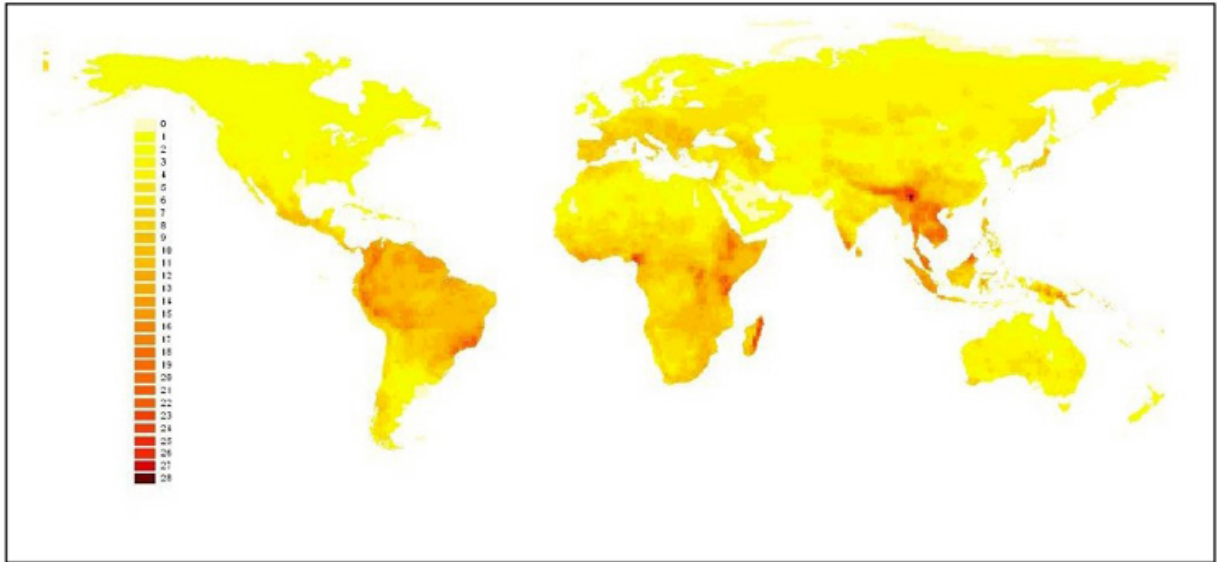


Figure 3. Patterns of distribution of all mammals considered at risk by IUCN (Modified from Ceballos et al., 2005). The column on the left indicates the number of species in 10,000 km² grid cells.

The current extinction crisis involves both species and populations, although the loss of populations is often neglected (Hughes et al. 1997; Ceballos and Ehrlich, 2002). Population extinctions are the prelude of species extinction, and a major component of the Sixth Biodiversity Extinction Crises. For example, in a recent analysis of the population losses of 177 mammal species from all continents, Ceballos and Ehrlich (2002) found that most species have lost between 50 to 100% of their populations, and estimated that more than 116,000 total populations have been lost. Similarly, the Living Planet Index from the World Wildlife Fund which monitors the population trends in 1,686 animal species indicates a 30% and 20% decline for mammals and birds, respectively, between 1970 and 2005 (Loh et al. 2008).

Clearly, even a crude estimate of population extinctions across all vertebrate groups will indicate a major biodiversity loss. Recently, we estimated that the number of “populations” of mammals and amphibians species classified as critically endangered, endangered, or threatened, is more than 30,000 (Ceballos et al., 2010).

VI. Consequences of the Sixth Extinction Wave

What does all this mean? The losses to humanity of the sixth extinction wave are potentially catastrophic. Humanity has, as far as we know, only one set of living companions in the universe. For many, if not most human beings, other organisms are endlessly interesting – as any pet lover, butterfly collector, bird-watcher, taxonomist of mites, or gardener can testify. Every bit of diversity lost represents a diminution of interesting features of our environment. Closely connected with that interest is the beauty that most of us see in biodiversity, whether in the shimmering structural colors of a morpho butterfly’s wing, the gorgeous red and green feathers of a Quetzal, the grace of a cheetah’s sprint, or the slow-motion progress of an amoeba moving under a microscope. And, of course, there are many people who believe that we have ethical responsibility not to casually exterminate other life-forms, the products of a magisterial evolutionary process that has continued for billions of years.

More important in the view of some is that populations and species of other organism are working parts of human life-support systems (Daily, 1997; Ehrlich and Daily, 1993). Multitudinous populations are responsible for supplying and maintaining vital ecosystem services from flood control, carbon sequestration, and nutrient recycling to generation of soils, pollination of crops, and control of agricultural pests (Millennium Ecosystem Assessment, 2003; Suzan et al. 2009). The sixth extinction wave thus not only threatens our esthetic and moral

senses, but the very survival of civilization. It seems certain that climate disruption will greatly increase the rate of population and species extinction. Small wonder that is why evolutionist Edward O. Wilson has called causing this extinction crisis “the folly our descendants are least likely to forgive us” (1984, p. 121)

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