

# CHAPTER 2

## Biological Extinction and Climate Change



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**Summary** What are the current dimensions of biological diversity? Taxonomists have described approximately two million species of eukaryotic organisms. Many more remain unknown, and the global total may approximate 12 million species or more. Generally, for the past 65 million years, the rate of extinction of these species appears to have been ~0.1 extinctions per million species per year. Now, however, as a result of human activities, it has increased by about 1000 times, to ~100 species per million per year. We are losing species at about 1000 times the rate at which new ones are evolving. Many species are local and particularly liable to extinction, with climate change and increasing human-related pressures of all kinds pushing very strongly on life as it exists. Most of the species cannot be saved by forming parks and protected areas or away from their natural habitats unless human pressures are lessened by general action among nations, a prospect that is not being well realized at present. The strong call for the preservation of biodiversity in the encyclical *Laudato Si'* represents the kind of ethical responsibility that must be adopted if there is to be any hope for the survival of our civilization.

### Background

This chapter presents the most up-to-date information on biological extinction. Its rate and intensity have made it increasingly urgent for us to create a sustainable planet. Our individual and collective greed and seeming inability or unwillingness to face reality are preventing our coming to grips with the problem, but there is no other solution than common action for the common good.

We depend on the communities of living organisms that have formed over hundreds of millions of years for our survival, and on the properties of individual kinds

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W. K. Al-Delaimy, V. Ramanathan, M. Sánchez Sorondo (eds.), *Health of People, Health of Planet and Our Responsibility*, [https://doi.org/10.1007/978-3-030-31125-4\\_2](https://doi.org/10.1007/978-3-030-31125-4_2)

of organisms for almost every aspect of our lives. There is no reason to think that the dimensions of the extinction crisis we are facing now will leave communities functioning properly to hold steady the qualities of the atmosphere, soils, or water, and no reason to think that we have already recognized all of the kinds of organisms that would be useful to us if we understood them and their properties better. That is why the following words expressed by Harvard biologist E.O. Wilson (1984, p. 121) are so very important for us to ponder:

The worst thing that will *probably* happen—in fact is already well underway—is not energy depletion, economic collapse, conventional war, or the expansion of totalitarian governments. As terrible as these catastrophes would be for us, they can be repaired in a few generations. The one process now going on that will take millions of years to correct is loss of genetic and species diversity by the destruction of natural habitats. This is the folly our descendants are least likely to forgive us.

Climate change is one of the major forces that will drive biological extinction in our time and by doing so will have an extraordinary and lasting detrimental effect on our collective health. In turn, any loss of species caused by other factors, including those discussed in this chapter, will have further detrimental effects not only now but permanently (Isbell et al., 2017). We depend on other species and the ecosystems they comprise for the air we breathe, the soil in which we grow our crops, the ability to absorb pollution, all of our food, many of our medicines, a major proportion of our building materials, and the beauty that surrounds us when we appreciate and protect it. In short, there is no factor that will harm human health and our ability to live sustainably on this planet more than the loss of biological diversity. While climate change and pollution are proving to be hugely damaging to human health directly, as amply illustrated by the rich diversity of chapters presented in this book, the loss of biological diversity and the natural systems it drives will prove much worse over the longer run. Biological extinction will be the worst legacy of climate change and pollution, as well as the most damaging to the continuation of our sustainable lives on earth and to our ability to maintain our health and our civilization in the near term.

It is difficult to estimate the current rate of extinction because in fact we know so little about the living world, even though our lives depend completely on its healthy functioning. As we shall discuss in this chapter, we have recognized and given names to a relatively small proportion of the total number of organisms on earth. We cannot even begin to understand the harm we are doing to ourselves by ignoring the loss of as many as half of them during the remainder of this century. Overall, the account presented here is based on the reviews of extinction presented in our February 2017 Study Week on Biological Extinction (Dasgupta & Ehrlich, 2019; Pimm & Raven, 2019) and in the outstanding paper in the same session by Lenton (2019). In the earth's 4.54 billion year history, life originated early and invaded the land about 400 million years ago. Our species, *Homo sapiens*, was first discovered in African fossils that were 300,000 years old, migrated to Eurasia at least 60,000 years ago, and reached all habitable continents by at least 15,000 years ago. Our spread and ultimate increase, discussed below, has had and is continuing to have a massive negative effect on all other forms of life on earth except for those we encourage for our own use.

## How Many Species Exist Now?

Our summary paper (Pimm & Raven, 2019), with others presented at the PAS/PASS meeting on biological extinction in February 2017, attempted to estimate the number of species that exist as well as to predict their rate of extinction. Most of the references for conclusions offered by us in that symposium will not be repeated here.

Science has discovered and named approximately two million species or organisms to date, and most of them remain poorly known. Judging from well-known groups of eukaryotes and their overall patterns of distribution, we might assume that at least 12 million species may actually exist. For marine eukaryotes, estimates vary greatly (Appeltans et al., 2012; Mora, Tottensor, Adl, Simpson, & Worm, 2011), with further investigations clearly necessary to arrive at realistic estimates. When it comes to prokaryotes, we cannot even guess the numbers of species reasonably; Locey and Lennon (2016) recently speculated that the total number of species of Eubacteria and Archaea might even amount to an astonishing one trillion. It would be well worth putting more effort into estimating their diversity and geographical specificity because they, as much or even perhaps more than eukaryotes, are clearly of fundamental importance for us both ecologically and economically (Montgomery & Bicklé, 2015). Whatever we learn about them is very likely to serve us well.

Most species that exist now are likely to become extinct before they are discovered, particularly in the tropics; thus, it will be important to choose our research and conservation directions very carefully during the coming decades. The record we shall be able to assemble is likely to be a limited representation of the richness of life as we know it now.

## Factors Driving Extinction

The key factors driving massive biological extinction in our time have resulted from the continuing, rapid growth of the human population in the roughly 11,700 years of the Holocene Epoch, a relatively warm time following the most recent glacial maximum. Early in the Holocene, our ancestors mastered agriculture. Over the subsequent 10,000 years or so, the total human population has grown from only about one million people to more than 7.6 billion; our numbers are estimated to keep growing to about 9.9 billion by mid-century ([www.prb.org](http://www.prb.org)). In contrast, when people began cultivating crops, there were fewer than 100,000 living in all of Europe! With the development of agriculture, however, early farmers began to be able to live together permanently in villages, towns, and ultimately cities. The inhabitants of such settlements could store enough food to carry them through unfavorable times. Living for the long term together in groups, individuals could for the first time specialize in various professions—the activities that together form the basis of our modern civilization. Everywhere in the world, forests began to be cut rapidly, with disastrous effects on biological diversity that have been greatly accelerated recently (e.g., Betts et al., 2017).

Particularly since the acceleration of the Industrial Revolution some 250 years ago, with its subsequent intensification of all our activities, the pollutants that we have produced have poisoned soils, waters, and the air we breathe, damaging our health and the natural systems that support us. Ultimately, the gasses our activities generate have begun to alter the world's atmosphere markedly and to drive major climate change that became evident about 75 years ago. Agriculture, urban sprawl, deforestation, and all of the activities associated with human population growth; the spread of invasive plants and animals, pests and pathogens; and the hunting and gathering of plants and animals from nature, have all damaged natural populations and sometimes driven them to extinction.

As our numbers have grown, our desire for enhanced consumption has grown even more rapidly. The Global Footprint Network ([www.footprintnetwork.org](http://www.footprintnetwork.org)) estimates that we are using approximately 175% of the world's sustainable productivity now, up from an estimated 70% in 1970—a situation that clearly cannot be sustained, and one in which the stronger nations will be led ever more forcefully to drain the potentially renewable resources from the poorer and weaker ones. Biological communities provide the basis of our lives, and the levels of species loss from them that we are experiencing therefore pose dangers for the sustainable functioning of life on earth (Duffy et al., 2017). Today, nearly 40% of Earth's land surface is devoted to farming and grazing, most of the latter unsustainable. One can only imagine how many species must have disappeared while agriculture was spreading over wide regions like the intensively cultivated, broadly defined Mediterranean region of western Eurasia and North Africa. At the same time, invasive species of animals and plants, pests and pathogens, are spreading around the world in ever-increasing numbers, out-competing others in the new regions that they have reached and often driving them to extinction.

Another significant driver of biological extinction, recognized from the 1950s onward, is anthropogenic climate change; methane, enormous quantities of carbon dioxide and other greenhouse gasses are being emitted into the atmosphere continuously. Reviewed elsewhere, the changes that we are experiencing are extremely dangerous, and our collective will to deal with them remains dangerously limited, with greed always a more attractive alternative for many. There is a great deal of urgency in coping strongly with this enormous threat, and Pope Francis' powerful encyclical *Laudato Si'* warns all of humanity to attend to the problem for our common benefit.

## Extinction Rates

With this review of the current factors driving extinction, we are enabled to return to a calculation of extinction rates now and in the future. The calculations that we presented in our earlier review were explicitly based on current records, the fossil record, and comparisons with rates of the origin of new species as determined by molecular phylogenies (Pimm & Raven, 2019). We express our estimates in terms

of extinctions per million species-years (E/MSY). With a historical extinction rate of approximately 0.1 extinctions per million species per year, we have now reached at least 1000 times that level, with the rates increasing rapidly.

Comparing International Union for Conservation of Nature (IUCN) Red List of Threatened Species ([www.iucnredlist.org/](http://www.iucnredlist.org/)) estimates of the likelihood of extinction for the species they include with other extinction probabilities leads to an estimate that perhaps 20% of all species in these groups may be in danger of extinction over the next several decades. At present observed extinction rates and a total of 12 million species of eukaryotes, about 60,000 of them might become extinct over the next 40 years. In sharp contrast, if 20% of all species were actually to become extinct during this period, 40 times that many, amounting to some 2.4 million, would have to be lost. Such a rate would amount to losing 60,000 species per year (higher in the future, lower now, of course). Considering that unknown species or poorly known ones are more likely to be rare and therefore on the average more likely to be in danger of extinction than those that have been rated, these huge numbers might actually be attained, but that will depend to a great extent on the nature and scale of human activities in the future. At any rate, the estimate is staggering!

Most species have relatively small ranges, and those that do are on the average in greater danger of extinction than common, widespread ones. Even the widespread ones are virtually never distributed uniformly and densely within the boundaries of their ranges, although that is often an implicit assumption in calculations. In addition, local species are usually also scarce even where they occur (Pimm & Raven, 2019). In his definition of biological “hot spots”—areas of high concentrations of endemic unusual species—Myers (1988) by definition included only those areas that had already lost 70% or more of their original vegetation to human activities and which had at least 2000 species of plants found nowhere else. Certainly such areas are likely to become important centers for extinction as human activities increase in intensity and in volume and conservations select and pursue the best goals for conservation they can define—intrinsically limited. Hotspots, therefore, are especially critical areas for future extinction, and ones where adequate conservation plans would be especially helpful in lowering future rates of extinction (Pimm & Raven, 2000). In comparing 25 hotspots using the data on original area, endemic bird or mammal species, and the current remaining natural vegetation (Crooks et al., 2017; Pimm & Raven, 2000), dismal futures are predicted for a high proportion of the species now living in these hotspots.

Considering the increasing number of factors that are driving species to extinction, it indeed seems plausible that 20% of them may disappear during the next several decades. If that is the case, and given the rates of extinction that would have been attained during the next few decades, it seems possible that a proportion of species amounting to roughly half of the total may vanish from nature by the end of the century (Pimm & Raven, 2017). Detailed analyses are provided by Ceballos et al. (2015, 2017) and Dasgupta and Ehrlich (2019), which support the idea that the rate of population is proceeding much more rapidly than we have realized. In addition, the well-documented shrinking of many populations of birds (Gross, 2015; Vorisek, Gregory, Van Strien, & Meyling, 2008; <http://www.stateofthebirds>.

[org/2017/wp-content/uploads/2016/04/2017-state-of-the-birds-farm-bill.pdf](http://www.stateofthebirds.org/2016/wp-content/uploads/2016/04/2017-state-of-the-birds-farm-bill.pdf); [http://www.stateofthebirds.org/2016/wp-content/uploads/2016/05/SotB\\_16-04-26-ENGLISH-BEST.pdf](http://www.stateofthebirds.org/2016/wp-content/uploads/2016/05/SotB_16-04-26-ENGLISH-BEST.pdf)) and insects (e.g., Hallmann et al., 2017; Vogel, 2017) appear to speak to the same point—human beings are simply taking up so much of the space that the numbers of other kinds of organisms must decrease and keep decreasing unless we find and deploy the means we need to maintain a sustainable world.

Regardless of what I consider to be a largely semantic problem, which is whether we have entered a major extinction event comparable with the earlier five the world has experienced (e.g., Baranosky et al., 2011), we are clearly living in times that have the potential to be catastrophic for our own future. In such a time, we must not lose hope, but rather strengthen our efforts to the extent to deal with scientifically demonstrated trends as effectively as we possibly can!

The least well understood factor that is driving future extinction is global climate change, a problem with which we are just starting to come to grips intellectually. Such rapid and catastrophic events would, of course, often be outside of the possibility of adaptation for the species concerned. Although the mechanisms underlying the relationship between climate change and extinction are complex (Pereira et al., 2010), some detailed, regional modelling exercises have been carried out in Australia (Williams, Jackson, & Kutzbach, 2007) and South Africa (Erasmus et al., 2002). These have led to predictions of the extinction of many species with restricted ranges during the coming decades in those areas. We do not understand yet how much climate change will add to biological extinction, and that of course depends in part on what actions we manage to take to slow down the change itself. Under any scenario, however, the current habitats of those species restricted to the southern edges of the southern continents will simply disappear, as will the habitats of those species restricted to the higher elevations in mountains worldwide, although they would have some opportunity for dispersal. Certainly, the rich arrays of endemic plants and other organisms that occur along the southern borders of Australia and Africa are in extreme danger of extinction from climate change.

Extinction rates during periods of rapid climate shift in the Pleistocene were not especially high, except in areas where humans were actively hunting populations of specific animals. As Lenton (2019) has pointed out, this observation would tend to suggest climate-caused extinction rates when the changes have been relatively extreme. A detailed review of estimates of extinction rates likely to occur in relation to climate change (Bellard et al., 2012) has shown a large degree of uncertainty with a number of factors still to be considered in detail. Thus, Lenton (2019) inquired to what extent the projected high levels of species loss would compromise the function of ecosystems and the biosphere, and found that massive changes are likely to occur. Changes of this magnitude could well result in the loss of entire biomes by the tipping of critical balance points. The massive changes in precipitation levels that are projected as part of global climate change, as from the Green Sahara of 6000 years ago to the sere desert of today, or from dense forests to deserts and savannas, could result from the overall pattern of change.

For the seas, projections of extinction rates are being developed slowly, with a relatively small proportion of marine organisms rated by the IUCN for degree of

threat. It is clear, however, that climate change with its accompanying acidification have become key factors in marine extinction. Overfishing is the most important of the obvious factors affecting extinction in the seas. Pollution from the land, historically chemical but now including the massive deposits of plastic, remains important and must certainly also be controlled if we want to maintain the productive seas that exist today. Our relatively poor knowledge of the extent of marine eukaryotic biodiversity makes estimates of extinction difficult, too, as Webb and Mindel (2015) have stressed.

Fortunately, efforts to measure and to ameliorate the environmental damage we are causing to the seas are growing (e.g., Sullivan et al., 2019). Certainly specific communities, such as coral reefs, attuned to narrow temperature ranges, appear to be in extreme danger of collapse (Hoegh-Guldberg et al., 2007; Hughes et al., 2017; Lucht et al., 2006). Marine anoxia resulting from the runoff of nitrogen and phosphorus from agricultural systems on land is leading to increased ocean warming and thus further reducing the capacity of the water to absorb oxygen. Summarizing, overfishing, habitat destruction, climate change, pollution, and ocean acidification (e.g., DeWeerd, 2017) are all contributing to extinction in the seas.

The possibility of even higher rates of climate warming than are generally assumed to be likely would of course have a much more damaging effect on biological diversity than anything discussed thus far in this chapter. A continuing disregard for our common welfare could lead to global temperate increases of 6 °C; if we reach such levels, or even higher ones, the consequences would be staggering. For example, Malin, Pinsky, and Jon Payne (personal communication) have pointed out that 10 °C warming at the time of the end Permian extinction drove more than 75% of the genera then in existence to extinction. This amounted to the most extensive extinction event in the history of our planet, permanently changing the character of life on earth. Regardless of whether we are wise enough to stop the process somewhere short of those levels, we are clearly facing major losses of biological diversity. That loss in turn will have an immediate and long-lasting effect on our civilization and our collective health both directly and indirectly. We must find effective ways to address the loss before it is too late (e.g., Lovejoy, 2017; Tilman et al., 2017).

## Conclusions

Nothing we are doing to damage the functioning of the living world and the stability of its ecosystems will do more harm than biological extinction. Curbing global climate change will be indispensable, but it is only one of the steps that we will need to take collectively if we wish to curb extinction and maintain a stable planet for our successors. Increasing human population and especially increased human greed for ever-higher levels of consumption will greatly increase future rates of extinction through the creation of a warmer world and in many other ways as well. We have estimated that as many as 2.4 million species of organisms, 20% of the estimated total, could become extinct during the next several decades as human pressures of all kinds intensify and



presently sustainable systems collapse, and that perhaps half of the estimated total number of species could be gone by the end of the twenty-first century.

As Dasgupta and Ehrlich (2019) have concluded, seeking to limit the proximate causes of extinction will not ultimately prevail unless the basic drivers are addressed—“continued population growth, policies seeking economic growth at any cost, overconsumption by the rich, and racial, gender, political, and economic inequality (including failure to redistribute). Collectively addressing these are possibly the greatest challenges civilization has ever faced.”

Achievement of the goals just outlined clearly must be taken as our common responsibility; without doing so, we simply have not got a chance. Learning about how to achieve these goals and then working to achieve them ultimately will be responsible for our survival. We must learn, teach, act, and vote in such a way as to advance our common cause, the search for a sustainable world. Doing so will require a degree of humility, compassion, and love that we have yet to exhibit, but which is indicated very clearly in our topical encyclical *Laudato Si'*. We must follow the example of Pope Francis in contemplating the beauty and importance of life as it is and the urgency of working to preserve it for the future.

**Acknowledgments** I have received helpful comments and discussion of this chapter from V. Ramanathan and Partha Dasgupta; Douglas H. Erwin, Smithsonian Institution; John F. Fitzpatrick, Cornell Laboratory of Ornithology; Jane Lubchenco and Jenna Sullivan, Oregon State University; Guy Midgley, Stellenbosch University; Camille Parmesan, University of Texas; Stuart Pimm, Duke University; Melin Pinsky, Rutgers University; Hugh Possingham, Nature Conservancy.

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