For any one species, extinction may seem catastrophic. But over the grand sweep of life on Earth, extinction is business as usual. Extinctions occur continually, generating a "turnover" of the species living on Earth. This normal process is called background extinction. Sometimes, however, extinction rates rise suddenly for a relatively short time — an event known as a mass extinction. Mass extinctions kill off many species, but the empty niches left behind may allow other lineages to radiate into new roles, shaping the diversification of life on Earth.

Eight mass extinctions are recognized in the Phanerozoic, and the same peaks are found for terrestrial and marine organisms, indicating that the major extinctions affected organisms on land and in the sea at the same time (Benton, 1995; Foote, 2003; Sepkoski, 1989; Figure 9.15). The Late Carboniferous, Late Jurassic, and Early Cretaceousextinctions are more prominent for terrestrial than marine organisms. Of the eight extinctions, five are considered major: end-Ordovician, end-Devonian, end-Permian, end-Triassic, and end-Cretaceous (Figure 9.16). Of these, the end-Permian extinction rate is highest, with a mean family extinction rate of 61% for all life, 63% for terrestrial organisms, and 49% for marine organisms (Benton, 1995). Peaks in origination of species generally follow extinction peaks by < 30 Myr, which appears to reflect the time necessary to fill abandoned ecological niches with new species (Figure 9.15).

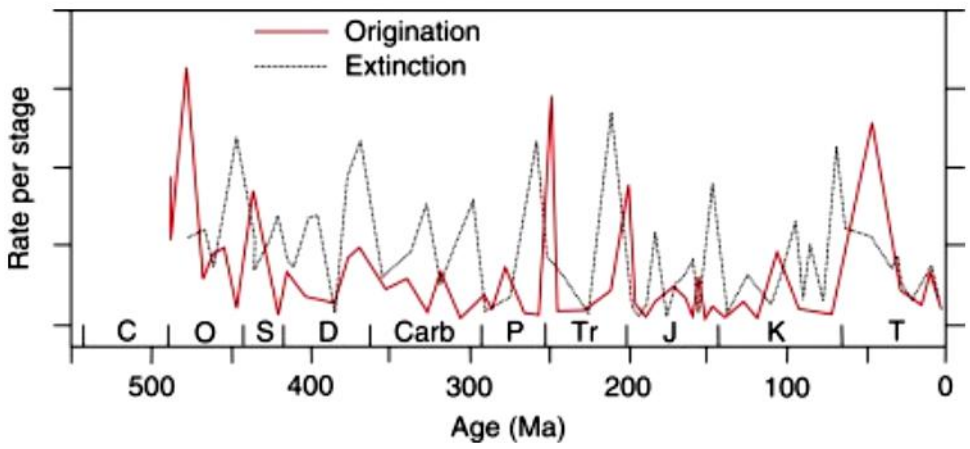


Figure 9.15. Rates of origination and extinction of marine animals during the Phanerozoic.

The five major mass extinctions marked in the fossil record occurred at irregular intervals, dating back almost half a billion years. The impact of these events was so profound that they often mark the boundaries of geologic time periods (Figures 9.1 and 9.2). The fossil layers older than the extinction contain plants and animals so different from the fossil layers after the extinction, and these differences are so widespread, that early geologists used them to mark off major periods in the Earth's history. This gives the extinction events some cumbersome names, but nongeologists can recall them by the life-forms that were lost and the time periods in which they occurred (Table 9.1).

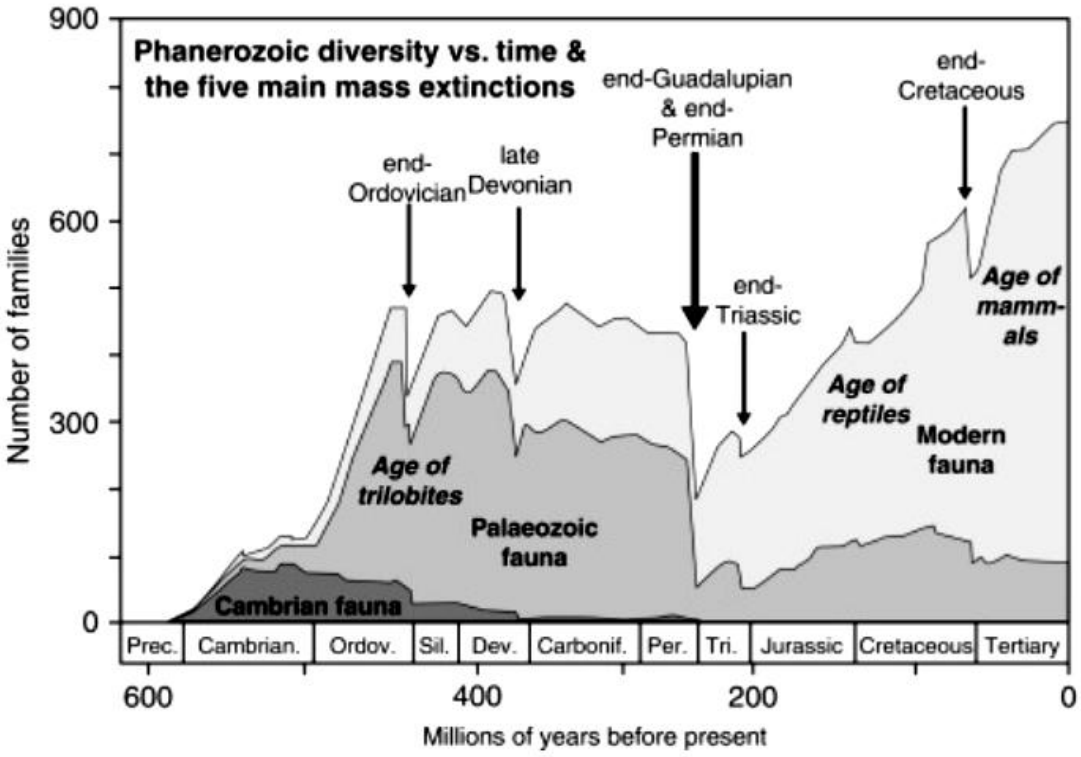


Figure 9.1 Major mass extinctions during the Phanerozoic showing number of families as a measure of biologic diversity. (From Metcalfe and Isozaki (2009)

The first mass extinction event happened approximately 440 million years ago (mya). At this time, life was concentrated in the seas and dominated by benthic marine organisms. The extinction event wiped out more than 100 families of marine life, including approximately half of all genera. Because it is difficult to identify species in fossils this old, these genus-level counts are more reliable than species estimates. After the extinction, surviving lineages diversified and overall marine species diversity slowly recovered. This oldest of all known extinction events is called the Ordivician–Silurian event.

Approximately 100 million years later—365 million years ago—another huge extinction event took place. This event was smaller than the Ordovician–Silurian but still catastrophic. Land plants had begun to evolve at this time, and sharks and bony fishes appeared in the oceans. Extinctions were focused on marine organisms, particularly reef-building corals and other marine invertebrates. This event may have occurred in a series of events; its timing is still being worked out. Its geologic name is the end-Devonian event. The worst mass extinction event occurred 250 million years ago (mya), wiping out 90% of all species (Figure 9.3). This was the third mass extinction, but it was the first to hit land species with major losses—more than half of all land species, mostly plants, were lost. This event marked the transition from the Permian to Triassic geologic periods and is called the Permian–Triassic or end-Permian extinction.

Table 9.1. The Five Largest Mass Extinction Events

Time Frame (Millions of Years Ago)	Geologic Marker	Biological Impact	Possible Cause
440	Ordovician–Silurian	100 families of marine life extinct, including half of all genera	Rapid cooling
365	End-Devonian	20% of all families lost, mostly marine organisms—perhaps in several episodes	Removal of CO_2 from the atmosphere after the emergence of land plants
250	Permian–Triassic	Extinction of 90% of all species—land and marine	Massive volcanism (Siberian Traps), methane release
200	End-Triassic	Loss of large amphibians	Unclear
65	Cretaceous–Tertiary (K–T)	Extinction of dinosaurs and many marine species	Extraterrestrial impact(s)

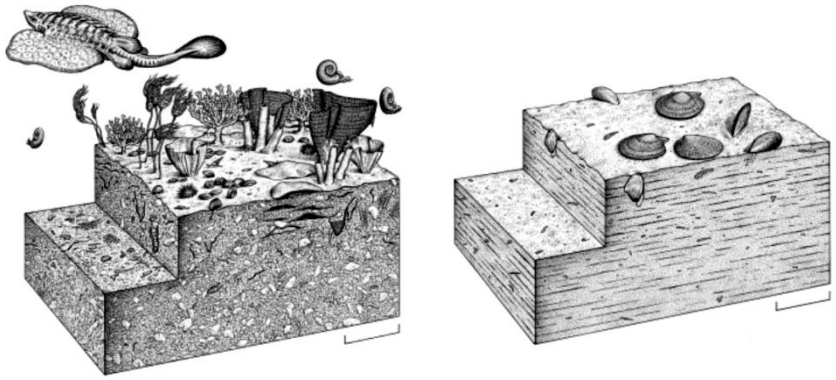


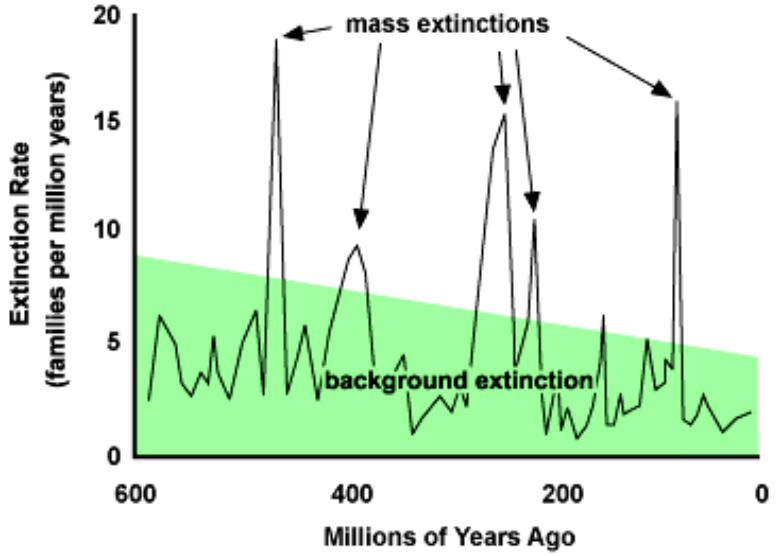
Figure 9.3. Marine benthic habitats before and after the Permian–Triassic extinction event. A marine fauna of 100 or more species is reduced to less than six species based on seabed reconstructions off south China.

Only 50 million years later, approximately 200 mya, another extinction spasm hit, this one affecting large terrestrial animals as well as plants and marine species. The end-Triassic event paved the way for the evolution of the dinosaurs by wiping out many large animals, mostly amphibians.

The most famous of the mass extinctions occurred 65 million years ago. This fifth and most recent event was dramatic in its abruptness and the thoroughness with which it eliminated all dinosaurs from the face of the planet. Only the clade that evolved into modern birds would survive. Dinosaurs had emerged as the dominant life-form among large animals since the extinction of the dominant large amphibians 135 million years earlier. They in turn were suddenly wiped out in this event, which took place at the Cretaceous–Tertiary boundary (abbreviated K–T following European spelling).

Along with these "big five" mega-extinction events, there have been multiple marked minor extinctions (see Fig. 9.2). The lesser extinction events are much less discussed, but they are still very significant. Many of them are linked to climate change, especially cooling episodes.

We have entered a 6th mass extinction. The 6th mass extinction (also referred to as the Anthropocene extinction) is an ongoing current event where a large number of living species are threatened with extinction or are going extinct because of the environmentally destructive activities of humans.



A species is extinct when no member of the species remains alive anywhere in the world. A species is extinct in the wild if it is only alive in captivity. A species is locally extinct or extirpated when it is no longer found in an area it used to inhabit but is still found elsewhere. A species is ecologically extinct if it persists in such reduced numbers that its effects on other species is negligible. Paleontologists estimate that most species "last" 1-10 million years • If we assume there are 10 million species, 1-10 species go extinct each year (0.00001% to 0.0001% per year).

CURRENT RATE OF AVIAN AND MAMMALIAN EXTINCTIONS • Global pool of about 15,300 well known species • Extinction rate is now documented to be about 2 species per year or 0.01% per year • Recall: background rate = 0.00001% to 0.0001% per year • Current rate is 100X to 1000X background rate • Assuming that less well known taxa have similar rates, we are experiencing the sixth mass extinction of life on earth.

Currently we're in the greatest period of mass extinction. Since 1600 over 1000 plant and animal species have gone extinct, a rate which is accelerating. Human activity contributes to 99% of all modern extinctions. You might think that well, this idea of extinction is natural and we, as humans, are species too, but we must consider the fact that most current extinctions are human driven (behaviorally, ethically, etc), and they are occurring at a very accelerated rate. It is this "rate" that is questionable, but there is no doubt that we are losing species faster than ever documented. Extinction is something that usually takes place slowly beginning with small isolated populations whose habitat deteriorates or they become unable to replace themselves. Local extinctions can occur when habitats are destroyed and any remaining habitat is full. These species are then restricted to marginal habitat and often cannot reproduce. Eventually if these members cannot find suitable habitat they will die of starvation or succumb to predation. As habitats become more fragmented smaller and smaller isolated populations exist. What results is inbreeding depression and genetic drift, which reduces any populations chance of increasing or further existence. Genetic drift is the random loss of gene frequency in a population. This occurs in all populations but is most detrimental in small isolated populations where individuals will eventually drift away from ancestral populations in terms of their genetic similarity. Genetic variability is key for populations in adapting to changing environments, but it can go too far. For instance, an important allele in a small population has a higher probability of being lost by chance with each new generation. A population of 10 individuals will retain 95% of its heterozygosity (=individuals possessing 2 different allele forms of the same gene, a measure of genetic variation) after 1 generation but after ten generations only 60% would be left. This would be without any immigration into the population which is often the case in small isolated populations. II. Two general types of extinction 1.)Background= typically continuous and low-level species extinction exists on earth which can be caused by environmental factors (climate change) or biological factors (predation or competition) 2.) Mass= loss of numerous species in a relatively short period of geological time. It can last for millions of years, but this is still considered short in terms of evolutionary time when we consider the earth is ~4.6 billion years old. Mass extinctions can also be caused by environmental or biological factors. Both of these are considered deterministic extinctions where there is some major change that the species cannot adapt to in time. Another sort of extinction is called stochastic which happens from normal and yet random changes in the environment. Such changes don't usually destroy a population but thin it out. As we are faced today with more and more small populations we will see stochastic extinction eventually leading to deterministic extinction. III. 5 Periods of Mass Extinction (overhead) Most well known is the K-T extinction when the dinosaurs went extinct. It is believed to have been caused by major environmental change that occurred after an asteroid impacted earth. Massive amounts of dust were forced into the atmosphere, blocking the sun, and eventually leading to global cooling. Currently in the 6th mass extinction in which we are loosing species at 10,000 times the rate of background extinction. IV. Human Caused The book goes into 2 different types of human caused extinctions: 1.) in water and on land 2.) on islands The distinction is important because islands represent a very small fraction of the earth's surface yet half of the extinctions over the last 400 years were island species. Many of these lost species were endemic to only a few islands. Endemic = lives only in location where it occurs naturally In general island species are endemic to a much smaller area and they are more geologically isolated, than are species living on mainland or in the oceans. Most threatened or endangered species face multiple threats. Here is a list that deals with some aspect of human caused or accelerated extinction V. Threats to Diversity and Losses of Species1.) Habitat Destruction 2.) Habitat Fragmentation 3.) Habitat Degredation 4.) Global Climate Change 5.) Overexploitation of Species for Human Use 6.) Invasion of Exotics 7.) Increased Spread of Disease Habitat Destruction, Fragmentation, and Degradation Examples include deforestation, desertification, road building, pollution, erosion All of which are most prominent where human populations are high and most of the original habitat has been destroyed. More than 50% of primary wildlife habitat has been lost in many Old World countries to agriculture, logging, and development. Over 50% of the earth's species are found in tropical rain forests even

though they only cover 7% of the total land surface. Fragments (board) are isolated land patches where more edge has been created. Large chunks of land are reduced and divided into multiple fragments. Such increased edge leads to fluctuations in light, temperature, humidity, and wind. Fragmented landscapes can also limit dispersal and colonization in both animals and plants (salamander example) especially plants that depend on animals to disperse their seeds. Eventually it leads to division of existing populations into smaller restricted subpopulations that are vulnerable to inbreeding depression and genetic drift. Global Climate Change The Greenhouse Effect has lead to increased global warming which in turn has multiple consequences. The most important in terms of species diversity is that it is happening so fast that most species do not have enough time to evolve with or adapt to the changes. Changes that will effect many species include rising sea levels, earlier arrival of the spring season, shifts in species ranges, increases in drought, fires, and heat waves. Overexploitation One example would be the harvesting of animals from their natural environments. Removal can occur for many reasons including hunting, subsistence, commercial use, poaching, and for trade. It usually becomes a problem when a commercial market develops for a previously unexploited species. Such commercial markets bring money and resources to more underdeveloped countries. The resources are then often extracted so thoroughly that it becomes rare, forcing the market to turn toward another species. These markets may include legal or illegal trade of fur, organs, food, and/or animals as pets. One example here in the US would be the extinction of the passenger pigeon (overhead). It was once thought to be the most abundant bird on earth but it was so thoroughly hunted with very few controls that the entire population of these birds was wiped out. (read passage) Exotic/Invasive Species (already discussed) Exotic = species occurring outside of its natural range due to human actions, but they do not become established because the new environment is not suitable to their needs. Invasive = species occurring outside of its natural range due to human actions that do establish themselves. They tend to increase their abundance at the expense of native species usually through the competition for a limited resource. Invasive species are a threat to 49% of all endangered species in the US Human activity that has lead to the introduction of invasive species includes: -European colonization (release of 100's of bird and mammal species to remind them of home, good example is the starling) -Horticulture and Agriculture (ornamentals and crops that escaped cultivation) -Accidental transports (weed seeds, rats, and diseases all in ship ballast {soil and water}) These new species do so well with the absence of their natural predators, pests, and parasites. They also tend to do well in altered or disturbed sites by better adapting than the native species. Diseases Often invasive species can introduce new diseases to native populations. The threat from diseases relates especially to captive wild populations. For instance the Black-Footed Ferret (overhead) is now only maintained as a captive population. This small genetically similar population was virtually wiped out when canine distemper was transmitted to them. A disease which the population had not evolved with and therefore had little defense against. In the wild we are seeing lower quality habitats which can eventually weaken the native populations increasing their susceptibility to disease or infections. With an increase in human animal contact we have started to see more spread of infections like HIV, which is present in cats, cows, monkeys, and humans.

Because not all species have equal probability of going extinct let's list broader characteristics of species that might cause them to go extinct: -species with narrow geographical ranges (island spp.) -species with 1 or few populations (San Clemente Sage Sparrow) -species with small population size (California Condor) -species that need large home ranges (Grizzly & Wolf) -species with large body sizes -ineffective dispersers (Silversword plant on edge of Hawaiian volcanoes) -little genetic diversity (Black-Footed Ferret) -specialized niche requirements (Northern Spotted Owl) -seasonal migrants (passerine birds dependent on 2 or more habitats)

The K-T extinction

The K-T extinction (Cretaceous-Tertiary extinction, 65 million years ago) is famous for killing off the dinosaurs (except birds, of course!), along with two-thirds of all species on Earth. However, small mammals, turtles, crocodiles, birds, redwood trees and many others survived.

There is very good evidence that a giant asteroid hit Earth at the same time as the K-T extinction. The smoking gun is the 100-mile wide crater it left behind off the coast of Mexico, along with disturbed geologic deposits (iridium and shocked quartz) consistent with an asteroid impact. The impact probably caused tidal waves, earthquakes, and clouds of dust so thick that they blotted out the sun for months. Such a disaster is certainly capable of causing a mass extinction. However, many lineages were on the wane, experiencing a lot of extinction, even before the asteroid hit. These pre-impact extinctions must have other causes.