The future of life on Earth

How large is our impact on life? If we disappeared, how long would it take for all traces of our existence to be eliminated? Assuming we continue on, what will be our impact on life and on our technological persistence? These questions have bearing on how long civilizations last and the detectability of intelligent life. In this lecture we will first take a fanciful journey into a future in which every human on Earth has vanished abruptly for some unspecified reason. We will then consider what is likely with humans continuing on.

A future without people

Human beings are unquestionably the dominant single species on the planet, and have been for millennia. But how strong is our influence? Various people have posed this question as a hypothetical: suppose that we all vanished tomorrow. How long would our structures last, and how would the remaining life adjust? For this part of the lecture I will draw heavily on the work of Alan Weisman as reported in Scientific American (July 2007) and a New Scientist article from October 2006. We will talk first about human structures, then discuss the effect on animal life.

A few days to weeks after disappearance

Within one or a few days our absence would be noted by blackouts at night due to the lack of fuel at certain power stations. Some that rely on renewable energy (e.g., solar or wind turbine energy) would last longer, but even they require maintenance. Typically the power would go away within weeks to months, although large structures such as the Hoover Dam might be able to operate for years before breaking down. Nuclear power plants would be especially susceptible, because they require water cooling systems that would likely fail within a few days. This would cause meltdowns at each of the more than 400 nuclear power plants worldwide.

This would be initially devastating for any local life, but the example of Pripyat, Ukraine suggests that the recovery might come more rapidly than we might think. This is a city that was completely abandoned after the 1986 disaster at the nuclear facility in Chernobyl. The buildings are crumbling, but after a few years in which rats and other vermin were the main life, wild boars, wolves, and other native fauna have re-entered and are doing well.

Cities with high-level groundwater would have immediate problems because without constant pumping there would be flooding. An obvious example is New Orleans, but New York City is another case in point. Prior to the founding of the city it was a swampy area crisscrossed with dozens of streams. Within two days of our departure, the subways would be flooded and this would spill over onto the streets (along with a huge mess of our garbage!). Sewers would also overflow, leading to rapid and widespread disease.

A few months to years after disappearance

With all the water spread by flooding, we know that the advent of winter will cause cracking. This will even happen in cities well above groundwater, due to rain. Indeed, this is another consequence of the special property of water that it expands when it freezes; the liquid can get into cracks, which are then expanded when ice forms. With people around there is continued maintenance of streets and buildings, but without us the damage would go unchecked. Homes and office buildings would suffer similar problems, although likely on a longer time scale. The cracks would then become home to weeds, which would continue the process. After enough time, larger plants would take over, leading eventually to trees. However, within the first few years evidence of cities would still be clear.

Another issue likely to rear its head within a few years is that of uncontrolled fires. Twigs and leaves from trees in city parks would remain uncollected, meaning that they would be vulnerable to fires started by lightning strikes. Accumulated garbage would continue these fires, and it is possible that a catastrophic conflagration would envelop most towns and cities within years after our vanishing. In addition to obviously destroying any wooden structures, these fires would weaken supports for other buildings.

A few decades to centuries after disappearance

In a place such as Manhattan, the flooding would by this point have had longer-term effects than mere cracking. Given that the skyscrapers typically have steel beam foundations anchored in bedrock, you might imagine that they would be stable for centuries. However, corrosion of the girders, combined with tilting of streets due to formation of streams and marshes, would likely cause them to topple within decades. The closely packed nature of the buildings in Manhattan means that having one fall could cause others to fall as well.

Within decades to centuries, virtually all roofs would have caved in. In addition, although bridges and dams are engineered to last for more than a hundred years each, this assumes constant maintenance. Without humans around, in decades bridges could collapse and dams would leak, first slightly and then eventually the rushing water would break them apart completely.

Thousands to millions of years after disappearance

The last remaining buildings would probably be those that are made of stone in dry environments. As an example, the pyramids of Egypt are up to 5,000 years old and still standing although beginning to break apart. Within thousands of years it is possible that a new ice age will emerge (although we can't predict this), and if so glaciers will roll over northern cities and wipe out evidence of their existence. Bronze sculptures, however, may in some circumstances last for millions of years. In addition, jewelry such as gold and diamonds is extremely resistant to wear and tear, and would probably be in nearly their current form millions of years from now.

Other aspects of our influence would also fade out on this time scale. For example, the lead deposited in our soil from 20th century automobiles would dissipate after, probably, around 30,000 years. Our carbon dioxide residue would take a similar time to dissipate, maybe 20,000 years, because although the surface layers of the ocean can soak up some of the CO_2, the deep layers will take thousands of years to adjust. Global warming would continue for a while after we left, and some people think that we are currently in a dangerous spiral, in which methane trapped in permafrost is being let out by warming. The methane would then add to the greenhouse effect and the spiral would continue. This is not certain, but it should be kept in mind that even if we stopped emitting greenhouse gases tomorrow the warming would still continue because the ocean is slow to respond.

If aliens landed a million years after we left, they might be able to deduce that an advanced civilization had been around by our landfills. Many plastics, such as polyvinyl chloride (which makes up gallon milk jugs) are not broken down at all by bacteria. In addition, our landfills are packed so tightly at their cores that very little decomposition takes place; newspapers protected from oxygen are still readable after decades, for example. The aliens could also note a mass extinction combined with obviously careful burial, with jewelry, of enormous numbers of bipeds.

Billions of years after disappearance

Over billions of years, tectonic movement will submerge most evidence of human existence except possibly in very stable areas such as Australia and the Canadian shield. There is, however, one piece of evidence that is guaranteed to be around a billion years from now: our artificial satellites in orbit. Around the Earth itself we have a number of satellites close enough to be in the outer wisps of our atmosphere. These are being dragged in gradually, and within a thousand years all will have re-entered and been destroyed. We also have many communications satellites at geostationary orbit (where the orbital time is 24 hours). These are far outside our atmosphere but over time will collide with each other and fragment, so they won't be around either. However, I think that if we really vanished tomorrow, we would undoubtedly have at least a few satellites orbiting Mars that survive for a billion years, barring the extremely unlikely possibility that one of them is hit by an asteroid. Aliens surveying our system at that point might conclude that we had evolved on Mars!

In the meantime, of course, the Sun would get steadily brighter. This would heat up the Earth, leading within a billion years to temperatures uncomfortable for liquid water over much of Eath's surface. Adaptation might be possible, however, in particular at the poles, so life could persist.

The effect on life of our disappearance

Backing up now, what would happen to animal and plant life after we vanished? Some animals would do well indeed. Birds would no longer run into skyscrapers and power lines. It has been estimated that a billion birds per year lose their lives in this way. Birds would also probably find productive new nesting sites in skyscrapers as windows fell apart. Mosquitoes would love the new New York and Washington, DC given that they would revert to their marshy origins. Feral house pets, especially cats, would emerge as formidable predators.

Some animals would actually suffer by our absence. Domestic cows, for example, would go from being protected to being steak on the hoof for the large predators that would start encroaching within a few years. Rats, the scourges of cities, would starve without our garbage and would be easy pickings for the raptors that would move in. Cockroaches would suffer as well. They are such common fixations in apartments because we provide them with warm homes during the winter. Without this, they would disappear from temperate locations.

Some endangered species would make comebacks without us to destroy their habitats. Others, however, would likely go extinct. An example is the Kirtland's warbler, which suffers major losses because brown cowbirds lay eggs in warbler's nests. Without humans to aggressively combat the cowbirds, the warblers might get wiped out. However, all in all, life would benefit dramatically from our departure.

Future life with humans: exponential growth

We now back all the way up and consider how life on Earth might go on if we do survive. Our influence is obviously accelerating, so as a first step we will consider what exponential growth means to resource usage.

Exponential, or geometric, growth means that over a fixed amount of time (say, one year) a quantity always increases by a given *factor*. If unchecked, this would lead to unlimited growth. However, something will always limit the growth, and in some cases that something will be rather nasty. The surprise is how rapidly the growth will be limited, so let's explore this in some detail.

First, the basic principle. Suppose that a quantity such as human population increases by 1% each year (the current estimate is actually between 1.1% and 1.2%). This means that after one year the quantity is 1.01 times what it started at; after two years the quantity is 1.0201 times the original value; after three years the quantity is 1.030301 times the original, and so on. These are small increases, however. What we'd like to know is how long it takes for a substantial increase, say a doubling.

The key to this is the "rule of 70". Suppose that over a year a quantity increases by x%. Then it will take approximately $70/x$ years for that quantity to double. For example, if population is increasing by 1% per year, then in 70 years the population will double. If the increase is instead 2% per year, then the doubling time is 35 years.

What does this imply? Let's say that the human population has a 1% growth rate. Over the next 793 years (the time since the signing of the Magna Carta), this would imply about 11.3 doublings, meaning that the current world population of 7.3 billion would swell to almost 17 trillion.

That may not be meaningful in itself; after all, the world's population has probably already increased by more than a factor of 2,000 since its steady-state value of 10,000 years ago, so maybe it could do it again. Think of it this way, though: if every one of those 17 trillion wanted to live at the level of the average American (with an energy usage of 10,000 Watts per person, which includes industrial and agricultural power), then the total power would equal everything the Earth gets from the Sun!

In reality we would reach our limits long before this. For example, for many years we saw the amount of oil extracted in the US decrease, and the price of gas increased as a result. Recently this has reversed due to more aggressive exploitation of other supplies, but the supply is still finite. Similarly, the Middle East has a much larger supply than we do, but exponential growth in population will always overwhelm finite resources. This is the argument by Thomas Malthus that Darwin used in his theory of evolution by natural selection. Yes, it is true that new resources have often been found, but this only delays rather than prevents the inevitable collapse that follows exponential growth.

With this background in mind, we will now consider some of the nearer-term effects of humans, and how these are likely to develop in the future.

Global warming

This is a topic that has received substantial political attention over the last several years. Part of the issue is that there are some strong special interests involved, which has taken what should have been a simple measurement and made it emotionally charged.

A fact which is not in dispute by reasonable people is that the average temperature of the Earth has been increasing over the last several decades. There are annual bumps and wiggles in the curve, as is expected when random variables are taken into account. For example, when Mt. Pinatubo erupted in 1991, the average global temperature dropped by about 0.4°C because of the soot that was thrown up in the atmosphere. There are also variations due to the solar cycle of sunspots. However, the long-term trend is a clear increase in temperature. In the last century, the global average temperature has risen by 0.74 ± 0.18°C. More troubling is that the rate of increase has gone up substantially: for example, since 1980 the average temperature has gone up by about 0.6°C.

The dispute has largely concentrated on two issues: (1) how much of this has been caused by human activity, particularly carbon dioxide emissions, and (2) are the long-term benefits to our cutting down on such emissions worth the short-term economic costs. By now, almost everyone agrees that CO_2 emission plays an important role, indeed probably the dominant role in the temperature rise. Climate projections are tricky, but estimates of the further warming range from 1°C to 6°C in the next century, depending both on our carbon emissions policy and the detailed climatic effects.

The economic pros and cons are much trickier to estimate because there are major uncertainties in both the costs of recent proposals such as the Kyoto Protocol and the gains from reduction of future sea rise and related effects. As there is no present consensus I will leave you to do your own research and draw your own conclusions. I will note, however, that some of the costs of our current trajectory are not easy to estimate. For example, it has been suggested that the increasing rate of severe hurricanes is due in part to the warmer ocean, which leads to lower-pressure systems and thus higher winds. It is also clear that many developing nations will be hit hardest by sea level rise; the temperature changes we've discussed may seem trivial, for example, but sea level rises of just a few centimeters lead to much more severe flooding, and some projections suggest a further rise of up to a meter in the next century.

What is your take on this issue?

Non-renewable resources

Part of the problem with an exponential growth in population is that many of the resources we use are not renewable. We will therefore run out of them eventually. For example, right now domestic oil production is at about 5 million barrels per day. This has been decreasing steadily since its peak in 1970, when it reached 9.5 million barrels per day, with the consequence that we now import twice as much oil as we produce. You've seen the result at the gas pumps. There is a lot more known oil under the Middle East, which is not exactly the most politically stable region, but even that supply will be drained within a few decades if current per-capita usage increases continue. More generally, about 87% of the world's energy production is from three non-renewable sources: petroleum, natural gas, and coal. Hydroelectric and nuclear power account for about 6% each, and everything else combined (geothermal, solar, wind, ...) make up just 1%.

Both the energy issue and global warming could in principle be addressed with solar energy or nuclear fusion (note that it is nuclear *fission* that is used in current reactors). These have benign waste products not involving carbon, and the potential energy supply is much larger. However, exponential population growth will ultimately lead to shortages no matter what. With such crowding and shortages are likely to come major problems, including the Four Horsemen: war, famine, disease, and death.

One political problem with such issues is that they are all relatively long-term. We are talking about decades to possibly hundreds of years before we run out of fossil fuels. Who cares? Indeed, in the 1970s there were a number of active attempts in the United States to promote birth control and alternate fuels, but these basically died out because to most people it seemed foolish to make significant adjustments when doom was so far away. Indeed, one could even argue (and some have) that if we were to make sacrifices on our own then other countries that do not make those sacrifices would gain a competitive advantage. It would take a worldwide effort.

What do you think?

Survival of civilizations and destiny in space

What does all this have to do with life in the universe? Without anything else to guide us it makes sense to assume that other advanced civilizations would face similar tradeoffs. Could it be that typical civilizations go through cycles like ours? Do they reach some technological peak and then collapse because of lack of resources? Or do they make adjustments that allow them to continue at a high level?

Sometimes when I talk to people about this I hear an argument that amazes me. There is a feeling that some have that all we really need to do is ramp up the space program so that we can take everyone off the Earth when things get too crowded or toxic or whatever. Then, we can spread out through the Solar System and eventually the universe, where the space and resources are essentially unlimited. So why worry?

This isn't a solution because it is so spectacularly expensive to launch people into space. Consider the Space Shuttle, which I remind you only goes into near-Earth orbit; it would be much more expensive to put people onto bases on the Moon, and overwhelmingly more expensive to send people to Mars. The cost of a single Shuttle mission wass about a billion dollars, and the Shuttle could hold seven people. Let's round this to a hundred million dollars per person. To put the population of Maryland, about 5.9 million people, into near-Earth orbit would therefore cost around 590 trillion dollars. The world gross domestic product is 85 trillion dollars, so even if the commercialization of space can reduce the cost per person to an incredible 10 million dollars for Moon and Mars flights, we're still out of luck. This is especially true given that the world annual population growth is 70 million at this time.

The net result is that we, and almost certainly any advanced alien civilization, will have to solve our problems on this world and not off of it. Our success, and the success of other species, has a large impact on how common and how communicative we expect other life to be.