Population
The Elephant in the Room

Introduction

At the root of all the converging crises in today's world is the issue of human overpopulation. Each of the global problems we face today is the result of too many people using too much of our planet's finite, non-renewable resources and filling its waste repositories of land, water and air to overflowing. The true danger posed by our exploding population is not our absolute numbers but the inability of our environment to cope with so many of us doing what we do.

It is becoming clearer every day, as crises like global warming, water, soil and food depletion, biodiversity loss and the degradation of our oceans constantly worsen, that the human situation is not sustainable. Bringing about a sustainable balance between ourselves and the planet we depend on will require us, in very short order, to reduce our population, our level of activity, or both. One of the questions that comes up repeatedly in discussions of population is, "What level of human population is sustainable?" In this article I will give my analysis of that question, and offer a look at the human road map from our current situation to that level.

As I have mentioned elsewhere, the concepts of ecological science are the most effective tools for understanding this situation. The crucial concepts are sustainability, carrying capacity and overshoot. Considered together these can give us some clue as to what the true sustainable population of the earth might be, as well as the trajectory between our current numbers and the point of sustainability.

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Sustainability

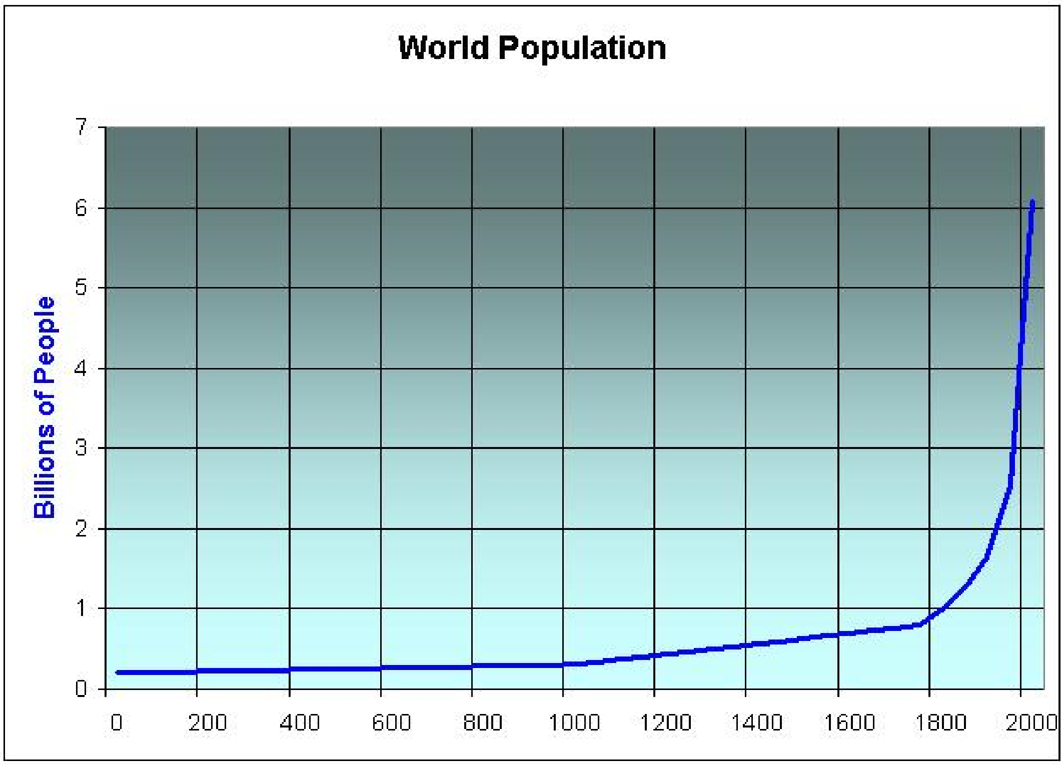
A sustainable population is one that can survive over the long term (thousands to tens of thousands of years) without either running out of resources or damaging its environmental niche (in our case the planet) in the process. This means that our numbers and level of activity must not generate more waste than natural processes can return to the biosphere, that the wastes we do generate do not harm the biosphere, and that most of the resources we use are either renewable through natural processes or are entirely recycled if they are not renewable. In addition a sustainable population must not grow past the point where those natural limits are breached. Using these criteria it is obvious that the current human population is not sustainable.

Carrying Capacity

In order to determine what a sustainable population level might be, we need to understand the ecological concept of *carrying capacity*. Carrying capacity is the population level of an organism that can be sustained given the quantity of life supporting infrastructure available to it. If the numbers of an organism are below the carrying capacity of its environment, its birth rate will increase. If the population exceeds the carrying capacity, the death rate will increase until the population numbers are stable. Carrying capacity can be increased by the discovery and exploitation of new resources (such as metals, oil or fertile uninhabited land) and it can be decreased by resource exhaustion and waste buildup, for example declining soil fertility and water pollution.

> **Note:** "*Carrying capacity*" used in its strict sense means the *sustainable* level of population that can be supported. This implies that *all* the resources a population uses are renewable within a meaningful time frame. An environment can support a higher level of population for a shorter period of time if some amount of non-renewable resources are used. If the level of such finite resources in the environment is very high, the population can continue at high numbers for quite a long time. Though some ecologists may cringe, I tend to think in terms of "sustainable carrying capacity" and "temporary carrying capacity". In this article I just use the single term "carrying capacity" to indicate the population level that can be supported by the environment at any moment in time. While not strictly correct, this does simplify and clarify the discussion.

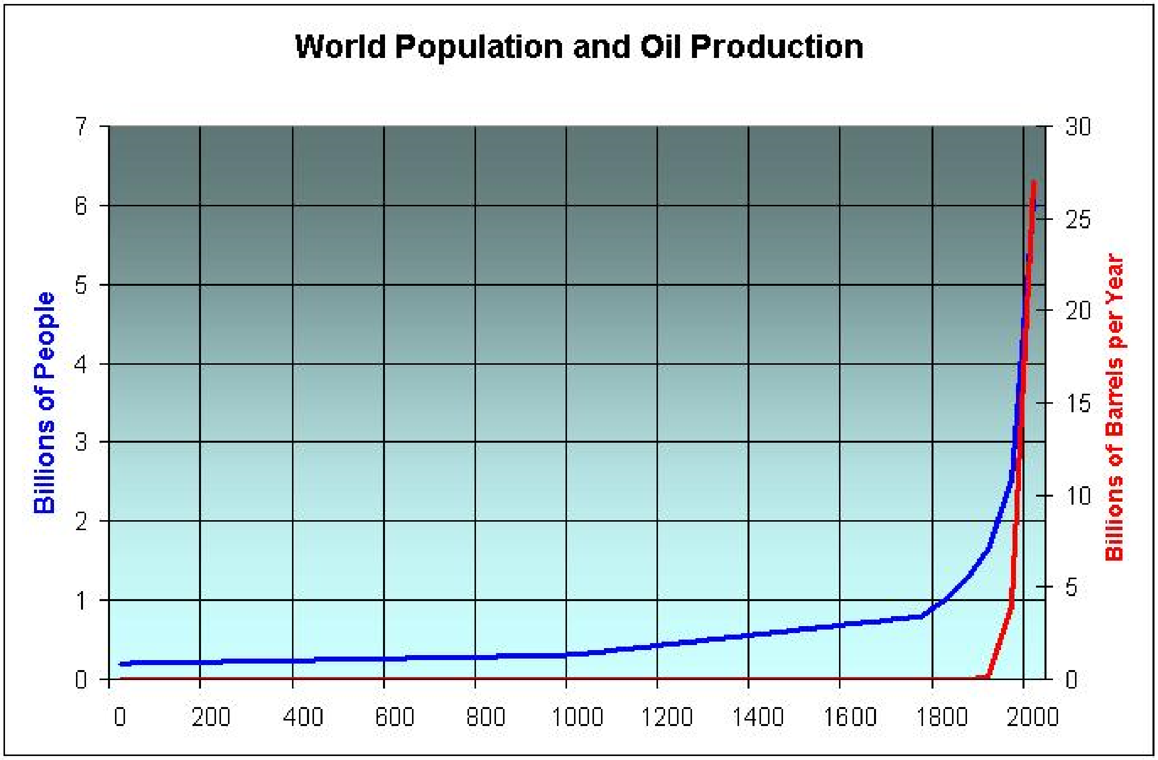
An increase in the carrying capacity of an environment can generally be inferred from a rise in the population inhabiting it. The stronger the rise, the more certain we can be that the carrying capacity has expanded. In our case a graph of world population makes it obvious that something has massively increased the world's carrying capacity in the last 150 years. During the first 1800 years of the Common Era, like the tens of thousands of years before, the population rose very gradually as humanity spread across the globe. Around 1800 this began to change, and by 1900 the human population was rising dramatically:



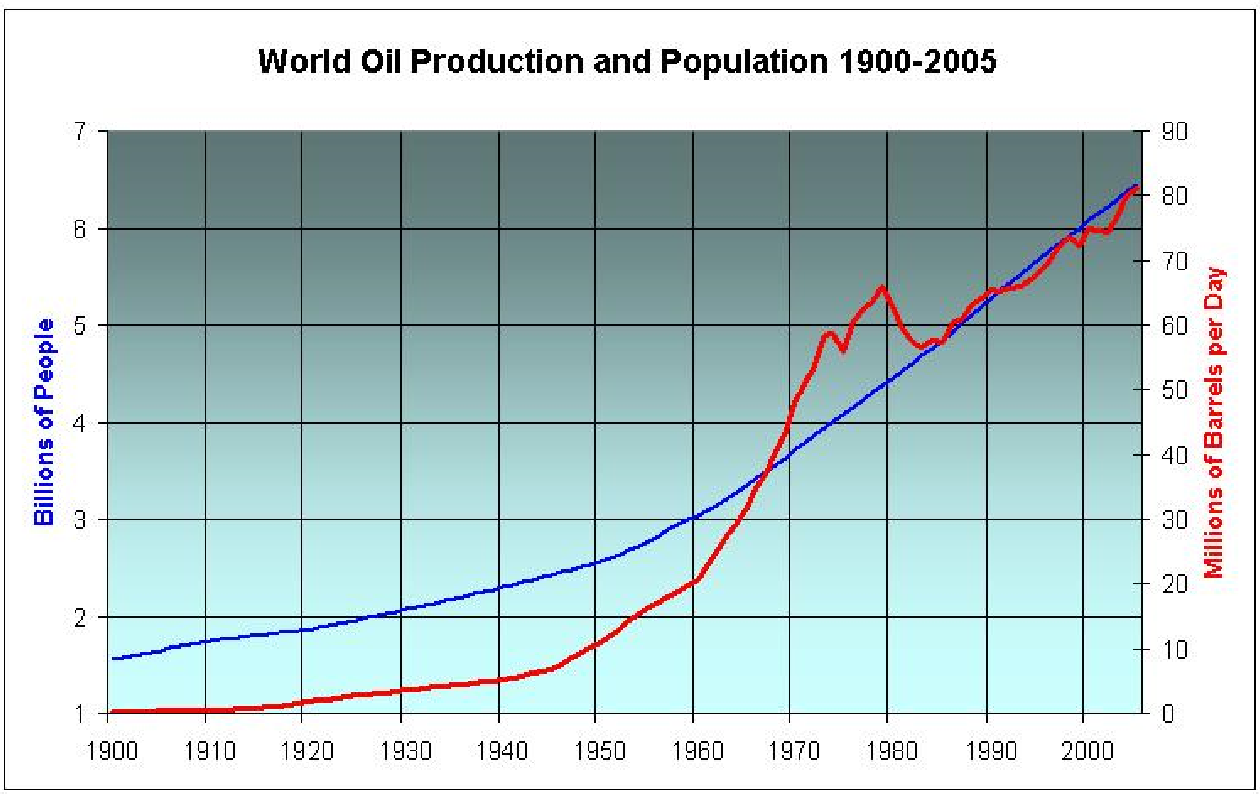
Part of the early phase of this expansion was due to the settlement of the Americas, but the exploitation of this fertile land in the 16th to 19th centuries would not seem to be enough on its own to support the population explosion we have experienced. After all, humans had already spread to every corner of the globe by 1900. There is something else at work here.

The Role of Oil

That something is oil. Oil first entered general use around 1900 when the global population was about 1.6 billion. Since then the population has quadrupled. When we look at oil production overlaid on the population growth curve we can see a very suggestive correspondence:



However, we have to ask whether this is merely a coincidental match. A closer look at the two curves from 1900 to the 2005 reinforces the impression of a close correlation:



The Food Factor

Are there other factors besides oil that may have contributed to the growth of the Earth's carrying capacity?

The main one that is usually cited is the enormous world wide increase in food production created by the growth of industrial agribusiness. There is no question that it has caused a massive increase in both yields and the absolute quantities of food being grown worldwide. While it has been celebrated with the popular label "The Green Revolution", there is nothing terribly miraculous about the process. When you open up that so-called revolution, you find at its heart our friend petroleum

Here's how it works. Industrial agriculture as practiced in the 20th and 21st centuries is supported by three legs: mechanization, pesticides/fertilizers and genetic engineering. Of those three legs, the first two are directly dependent on petroleum to run the machines and natural gas to act as the chemical feedstock. The genetic engineering component of agribusiness generally pursues four goals: drought resistance, insect resistance, pesticide resistance and yield enhancement. Meeting that last goal invariably requires mechanical irrigation, which again depends on oil.

Even more than other oil-driven sectors of the global economy, food production is showing signs of strain as it struggles to maintain productivity in the face of rising population, flattening oil production and the depletion of essential resources such as soil fertility and fresh water. According to figures compiled by the Earth Policy Institute, world grain consumption has exceeded global production in six of the last seven years, falling over 60 million tonnes below consumption in 2006. Global grain reserves have fallen to 57 days from a high of 130 days in 1986. After keeping pace with population growth from 1960 until the late 1980s, per capita grain production has shown a distinct flattening and declining trend in the last 20 years.

At its heart the "Green Revolution" is yet another example of the enormous usefulness of oil. Without large quantities of cheap oil, this revolution could not have occurred. The simple fact published in a University of Michigan study in 2000 that every calorie of food energy consumed in the United States embodies over seven calories of non-food energy (and other studies that have placed the ratio at 10:1) make the linkage clear. The United States currently uses over 12% of its total oil consumption for the production and distribution of food. As the oil supply begins its inevitable decline, food production will be affected. While it is probable that most nations will preferentially allocate oil and natural gas resources to agriculture by one means or another, it is inevitable that over the next decades the food supply key to maintaining our burgeoning population will come under increasing pressure, and will be subject to its own inescapable decline.

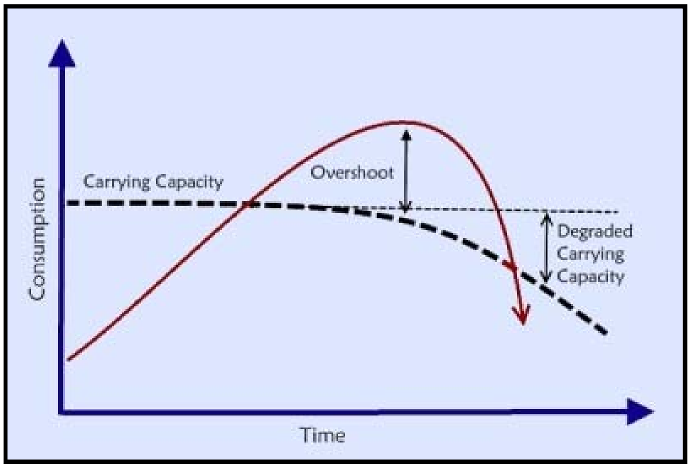
Carrying Capacity: Conclusion

Oil and its companion natural gas together make up about 60% of humanity's primary energy. In addition, the energy of oil has been leveraged through its use in the extraction and transport of coal as well as the construction and maintenance of hydro and nuclear generating facilities. Oil is as the heart of humanity's enormous energy economy as well as at the heart of its food supply. The following conclusion seems reasonable:

Humanity's use of oil has quadrupled the Earth's carrying capacity since 1900.

Overshoot

In ecology, overshoot is said to have occurred when a population's consumption exceeds the carrying capacity of its environment, as illustrated in this graphic:



When a population rises beyond the carrying capacity of its environment, or conversely the carrying capacity of the environment falls, the existing population cannot be supported and must decline to match the carrying capacity. A population cannot stay in overshoot for long. The rapidity, extent and other characteristics of the decline depend on the degree of overshoot and whether the carrying capacity continues to be eroded during the decline, as shown in the figure above. William Catton's book "Overshoot" is recommended for a full treatment of the subject.

There are two ways a population can regain a balance with the carrying capacity of its environment. If the population stays constant or continues to rise, per capita consumption must fall. If per capita consumption stays constant, population numbers must decline. Where the balance is struck between these endpoints depends on how close the population is to a subsistence level of consumption. Those portions of the population that are operating close to subsistence will experience a reduction in numbers, while those portions of the population that have more than they need will experience a reduction in their level of consumption, but without a corresponding reduction in numbers.

Populations in serious overshoot *always* decline. This is seen in wine vats when the yeast cells die after consuming all the sugar from the grapes and bathing themselves in their own poisonous alcoholic wastes. It's seen in predator-prey relations in the animal world, where the depletion of the prey species results in a die-back of the predators. Actually, it's a bit worse than that. The population may actually fall to a lower level than was sustainable before the overshoot. The reason is that unsustainable consumption while in overshoot allowed the species to use more non-renewable resources and to further poison their environment with excessive wastes. It is a common understanding of ecology that overshoot degrades the carrying capacity of the environment (as illustrated in the declining "Carrying Capacity" curve in the above figure). In the case of humanity, our use of oil has allowed us to perform prodigious feats of resource extraction and waste production that would simply have been inconceivable before the oil age. If our oil supply declined, the lower available energy might be insufficient to let us extract and use the lower grade resources that remain. A similar case can be made for a lessened ability to deal with wastes in our environment

It is important to recognize that humanity is not, overall, in a position of overshoot at the moment. Our numbers are still growing (though the rate of growth is declining). However, we are getting obvious signals from our environment that all is not well. These signals seem to be telling us we are approaching the maximum carrying capacity. If the carrying capacity were to be reduced as our numbers continued to grow we could find ourselves in overshoot rather suddenly. The consequences of that would be quite grave.

An Image of Overshoot

The predicament of a population entering overshoot is illustrated by a short scene from the children's cartoon series about Wile E. Coyote and the Road Runner.

As the scene opens, our hero, Wile E. Coyote, is zooming hungrily across the top of a mesa, propelled by the exuberant blast of his new Acme Rocket Roller Skates. Suddenly a sign flashes into view. It reads, "Danger: Cliff Ahead." The coyote tries desperately to change course, but his speed is too great and rocket roller skates are hard to control at the best of times. Just before the edge of the cliff the rocket fuel that was sustaining his incredible velocity runs out; the engines of his roller skates die with a little puff of smoke. The coyote begins to slow but it's too late, his inertia propels him onward. Suddenly the ground that moments before had ample *capacity to carry him* in his headlong flight falls away beneath him. As he *overshoots* the edge high above the canyon floor, he experiences a horrified moment of dawning realization before nature's impersonal forces take over.

The Role of Peak Oil

As we all know but are sometimes reluctant to contemplate, oil is a finite, non-renewable resource. This automatically means that its use is not sustainable. If the use of oil is not sustainable, then of course the added carrying capacity the oil has provided is likewise unsustainable. Carrying capacity has been added to the world in direct proportion to the use of oil, and the disturbing implication is that if our oil supply declines, the carrying capacity of the world will automatically fall with it.

These two observations (that oil has expanded the world's carrying capacity and oil use is unsustainable) combine to yield a further implication. While humanity has apparently not yet reached the carrying capacity of a world *with* oil, we are already in **drastic overshoot** when you consider a world *without* oil. In fact our population today is at least five times what it was before oil came on the scene, and it is still growing. If this sustaining resource were to be exhausted, our population would have no option but to decline to the level supportable by the world's lowered carrying capacity.

What are the chances that we will experience a decline in our global oil supply? Of course given that oil is a finite, non-renewable resource, such an occurrence is inevitable. The field of study known as Peak Oil has generated a vast amount of analysis that indicates this decline will happen soon, and may even be upon us right now.

Individual oil fields tend to show a more or less bell-shaped curve of production rates - rising, peaking and then falling. Once a field has entered decline it has been found that no amount of remedial drilling or new technology will raise its output back to the peak rate. The theory of Peak Oil says that the world's oil production can be modeled as a single, enormous oil field, and will therefore exhibit this same production curve. It is intuitive that if all the oil fields in the world enter decline, and insufficient replacement fields can be found and developed, the world's production will decline.

The signals of Peak Oil are all around for those who know what to look for: the continuing two-year-old plateau in the world's conventional crude oil production; the crash of Mexico's giant Cantarell oil field last year; the U.K. slipping from being an oil exporting nation to a net importer in 2005; the fact that three of the world's four largest oil fields are confirmed to be in decline; the analysis on The Oil Drum of Saudi Arabia's super-giant Ghawar field that indicates it may be teetering on the brink of a crash; the fact that over two thirds of the world's oil producing nations are experiencing declining production; delays and cost overruns in new projects in the Middle East, Kazakhstan and Canada's tar sands. To make matters worse, according to several analyses including a very thorough one done by a PhD candidate in Sweden, the addition of new projects is unlikely to delay the terminal decline by more than a few years.

Understanding the role of oil in expanding the earth's carrying capacity brings a new urgency to the topic of Peak Oil. The decline in oil supply will reduce the planet's carrying capacity, thus forcing humanity into overshoot with the inevitable consequence of a population decline. The date of the peak will mark the point at which we should expect to see the first effects of overshoot. The rapidity of the decline following the peak will determine whether our descent will be a leisurely stroll down to the canyon floor or a headlong tumble carrying a little sign reading, "Help!"

Time Frame and Severity

The first questions everyone one asks when they accept the concept of Peak Oil is, "When is it going to happen?" and "How fast is the decline going to be?" Peak Oil predictions are hampered by the lack of data transparency by many oil producers. They are reluctant to publish verifiable reserve figures, field-by-field production numbers, or observations of the performance of individual oil fields. As a result the fully correct answer to both questions is, "We don't know yet." This isn't the whole answer, though. As with many predictions we can specify probable ranges based on the current evidence, observed trends over the last few years and published future development and production plans. The guesses are becoming more and more educated as time goes by.

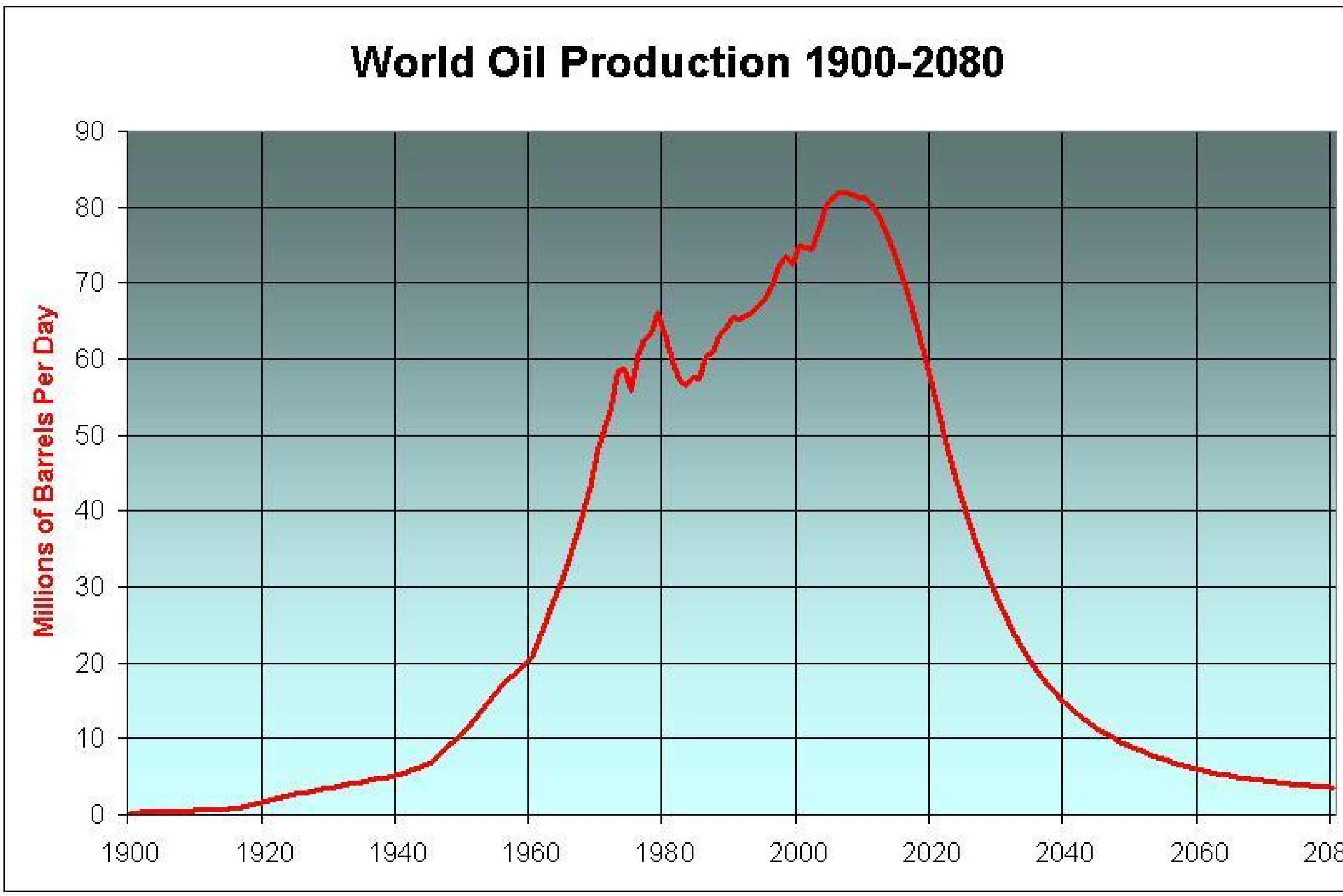
Several "heavy hitters" in the Peak Oil field have said the peak has already happened. These include Dr. Kenneth Deffeyes (a colleague of Dr. M. King Hubbert), major energy investor T. Boone Pickens, energy investment banker

Matthew Simmons (who first sounded the alarm about Saudi Arabia's impending depletion) and Samsam Bakhtiari, a retired senior expert with the National Iranian Oil Company.

The steepness of the post-peak decline is open to more debate than the timing of the peak itself. There seems to be general agreement that the decline will start off very slowly, and will increase gradually as more and more oil fields enter decline and fewer replacement fields are brought on line. The decline will eventually flatten out, due both to the difficulty of extracting the last oil from a field as well as the reduction in demand brought about by high prices and economic slowdown.

The post-peak decline rate could be flattened out if we discover new oil to replace the oil we're using. Unfortunately our consumption is outpacing our new discoveries by a rate of 5 to 1. to make matters worse, it appears that we have probably already discovered about 95% of all the conventional crude oil on the planet.

A full picture of the oil age is given in the graph below. This model incorporates actual production figures up to 2005 and my best estimate of a reasonable shape for the decline curve. It also incorporates my belief that the peak is happening as we speak.



Maintaining Our Carrying Capacity

The consequences of overshoot might be avoided if we could find a way to maintain the Earth's carrying capacity as the oil goes away. To assess the probability of this, we need to examine the various roles oil plays in maintaining the carrying capacity and determine if there are available substitutes with the power to replace it in those roles. The critical roles oil and its companion natural gas play in our society include transportation, food production, space heating and industrial production of such things as plastics, synthetic fabrics and pharmaceuticals. Of these the first three are critical to maintaining human life.

Transportation

Peak Oil is fundamentally a liquid fuels crisis. We use 70% of the oil for transportation. Over 97% of all transportation depends on oil. Full substitutes for oil in this area are unlikely (I'd go so far as to say impossible). Biofuels are extremely problematic: their net energy is low, their production rates are also low, their environmental costs in soil fertility are too great. Crop based biofuels compete directly with food, while cellulosic technologies risk "strip mining the topsoil" at the production rates needed to offset the loss of oil. Electricity will be able to substitute in some applications such as trains, streetcars and perhaps battery powered personal vehicles, though at significant cost in terms of both flexibility and economics. There is no realistic substitute for jet fuel.

Food

Oil is used in tilling, planting, weeding, harvesting and transporting food, as well as in pumping water for crop irrigation. Natural gas is used to make the vast quantities of fertilizer required to support our industrial, monoculture agribusiness system. As oil and natural gas decline, global food output will fall. This will be offset to some degree by the adoption of more effective and less resource-intensive farming practices. However, it is not clear that such practices could maintain the enormous food production required, especially as much of the world's farmland has been decimated by long term monocropping and will require fertility remediation to produce adequate crops without fertilizer inputs.

Heat

In northern climates the fuel of choice for building heat is natural gas. Gas is on its own imminent "peak and decline" trajectory, made worse by the fact that it is harder to transport around the world than oil. The only realistic replacement for natural gas is electric heat. It is quite possible that the rapid adoption of electric resistance heating in cold climates could lead to a destabilization of under-maintained and over-used distribution grids, as well as localized shortages of generating capacity. While there are technologies that will allow us to increase the generation of electricity, they all have associated problems - coal produces greenhouse gases, nuclear power produces radioactive waste and is politically unpalatable in many countries and solar photovoltaic is still too expensive. Wind power is showing promise, but is still hampered by issues of scale and power variability.

I think that we will strive mightily to produce alternative energy sources to maintain the carrying capacity, but I am convinced we will ultimately fail. This is due to issues of scale (no alternatives we have come up with so far come within an order of magnitude of the energy required), issues of utility (oil is so multi-talented that it would take a large number of products and processes to fully replace it), issues of unintended consequences (as is currently being recognized with biofuels) and issues of human behaviour (a lack of international cooperation is predicted by The Prisoner's Dilemma, and behaviours such comfort-seeking, competition for personal advantage and a hyperbolic discount function are planted deep in the human genome as explained in Reg Morrison's "The Spirit in the Gene" and in my article on Hyperbolic Discount Functions).

We will be able to replace some small portion of the carrying capacity provided by oil, but in the absence of oil it is not clear how long such alternatives will remain available, relying as they do on highly technical infrastructure that currently runs on oil like everything else.

Implications

Given the fact that our world's carrying capacity is supported by oil, and that the oil is about to start going away. it seems that a population decline is inevitable. The form it will take, the factors that will precipitate it and the widely differing regional effects are all imponderables. Some questions that we might be able to answer (though with a great degree of uncertainty) are "When will it start?", "When will it end?", "How much control will we have?", "How bad will it be?" and "How many people will be left?" The rest of this article is devoted to a high-level population model that attempts to address these questions.

A Simple Model of Population Decline

Parameters

To set the parameters of our model, we need to answer the four questions I posed above.

When Will The Decline Start?

This depends entirely on the timing of Peak Oil. My conclusion that the peak is occurring now makes it easy to pick a start date. The model starts this year, though a start date five or ten years from now would not affect the overall picture.

When Will it End?

Given that oil is a primary determinant of carrying capacity, the obvious answer is that the situation will stabilize when the oil is gone. The oil will never be *completely*

Based on the model in the figure above I chose an end date of 2082, 75 years from now.
gone of course, so we can modify that to read, "When oil is unavailable to most of humanity." We know that point will come, because oil is a finite, non-renewable resource, but when will that be?

How Much Control Will We Have?

Will we be able to mitigate the population decline rate through voluntary actions such as reducing global fertility rates, and making the oil substitutions I mentioned above.

I have decided (perhaps arbitrarily) that the oil substitutions would not affect the course of the decline, but would be used to determine the sustainable number of people at the end of the simulation.

Fertility rates are an important consideration. The approach I've taken is to model the net birth rate, the combination of natural fertility and death rates that give us our current global population growth of 75 million per year. I modified that by having it decline by 0.015% per year. This reflects both a declining fertility rate due to environmental factors and some degree of women's education and empowerment, as well as a rising death rate due to a decline in the the global economy. I do not think that traditional humane models such as the Benign Demographic Transition theory will be able to influence events, given that the required economic growth is likely to be unavailable.

How Bad Will It Be?

This question comes from the assumption that the decline in net births alone will not be enough to solve the problem (and the simulation bears this out). This means that some level of excess deaths will result from a wide variety of circumstances. I postulate a rate of excess deaths that starts off quite low, rises over the decades to some maximum and then declines. The rise is driven by the worsening global situation as the overshoot takes effect, and the subsequent fall is due to human numbers and activities gradually coming back into balance with the resources available.

How Many People Will Be Left?

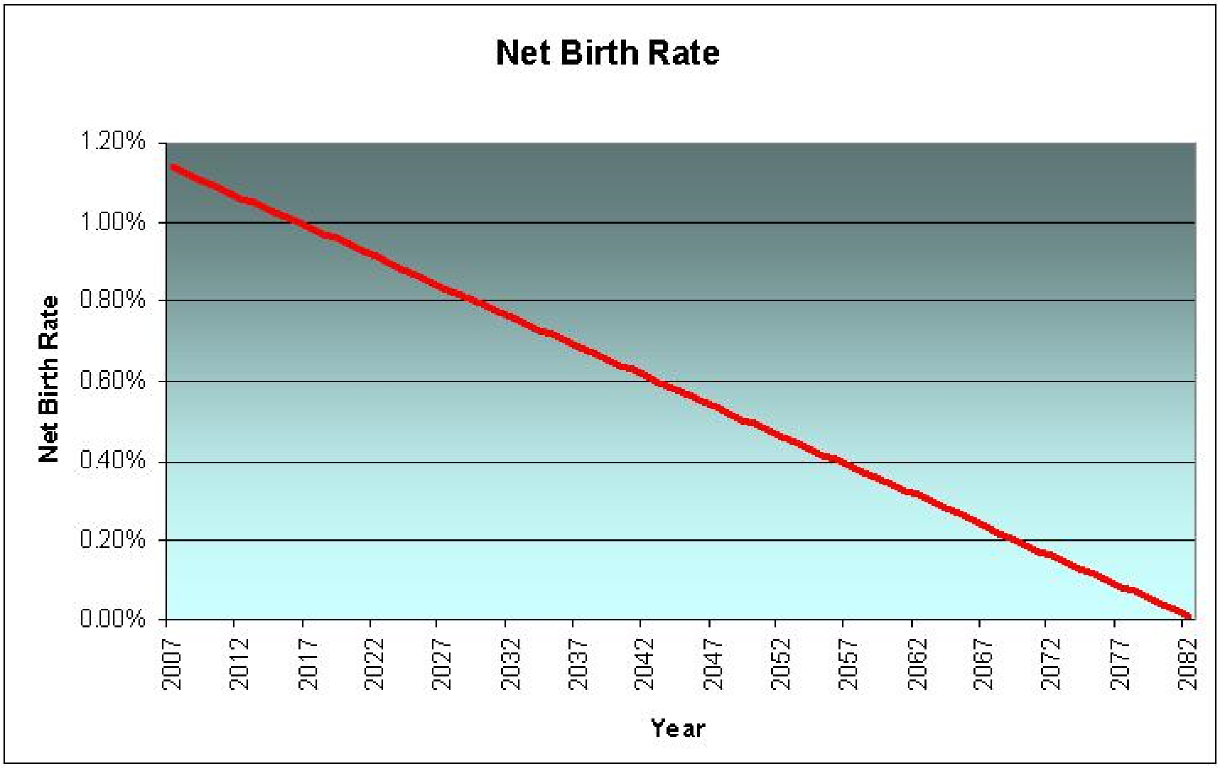
Taking the carrying capacity effects discussed above into account, I initially set the bar for a sustainable population at the population when we discovered oil in about 1850. This was about 1.2 billion people. Next I subtracted some number to account for the world's degraded carrying capacity, then added back a bit to account for our increased knowledge and the ameliorating effects of oil substitutes. This is a necessarily imprecise calculation, but I have settled on a round number of **one billion** people as the long-term sustainable population of the planet in the absence of oil.

Comments

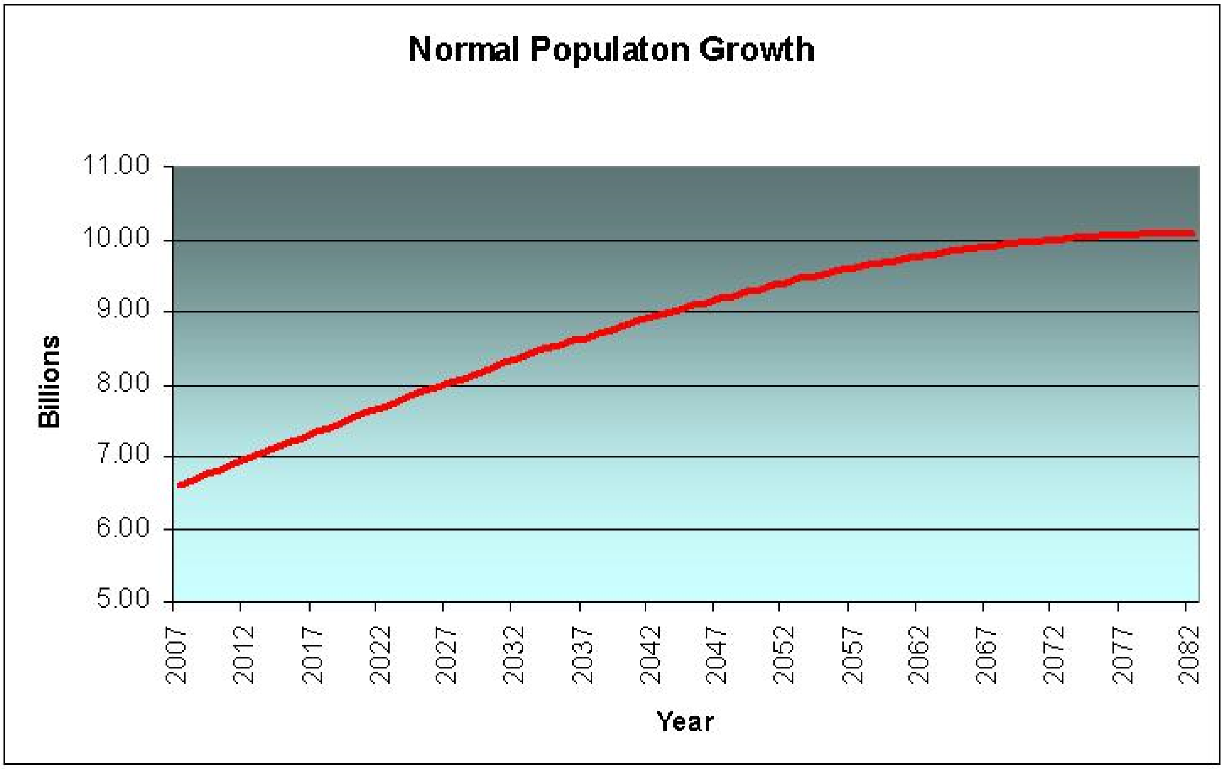
The model is a simple arithmetical simulation that answers the following question: "Given the assumptions about birth and death rates listed above, how will human population numbers evolve to get from our current population of 6.6 billion to a sustainable population of 1 billion in 75 years?" It is not a predictive model. It is aggregated to a global level, and so can tell us nothing about regional effects. It also cannot address social outcomes. Its primary intent is to allow us to examine the roll that excess deaths will play in the next 75 years

The Model

We will start by graphing the net birth rate over the period 2007 to 2082, incorporating a 0.015% annual decline: As you can see, the net birth rate declines to zero by 2082.

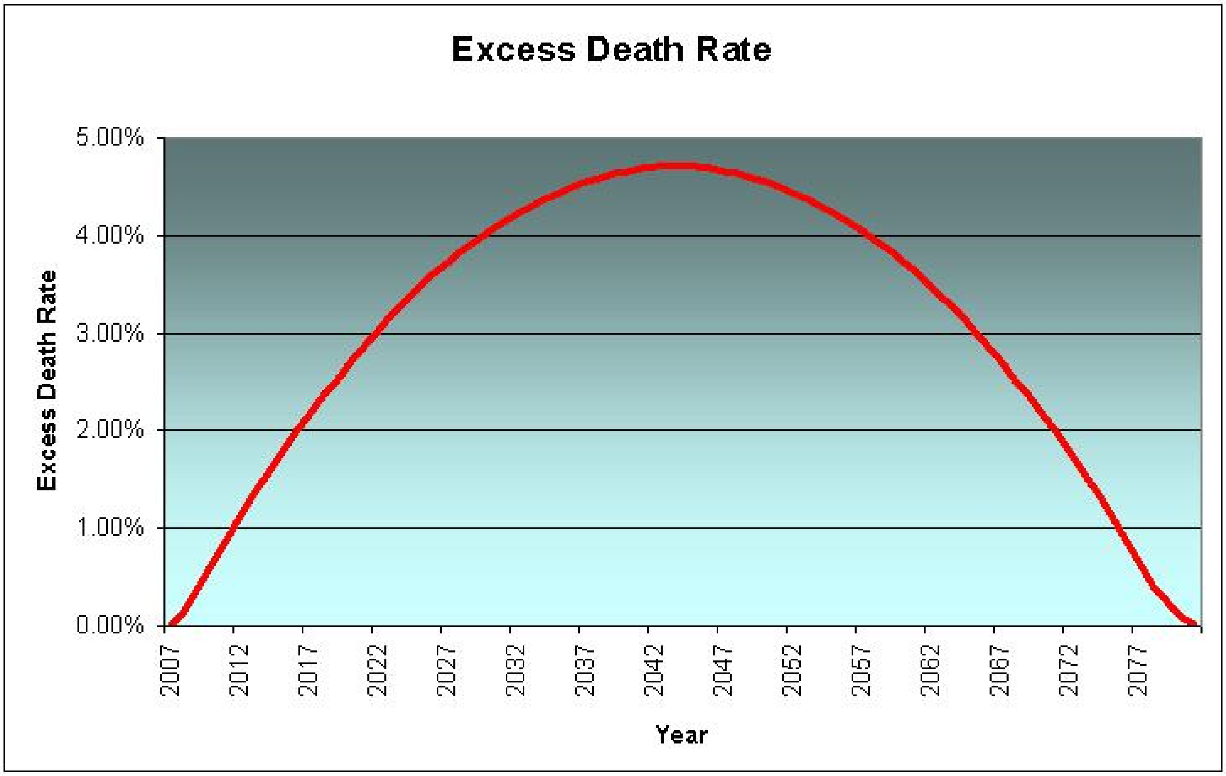


Is it possible that this declining birth rate will get us closer to our sustainable population goal of one billion? The following graph shows our population growth with the effects of the declining net birth rate shown above:

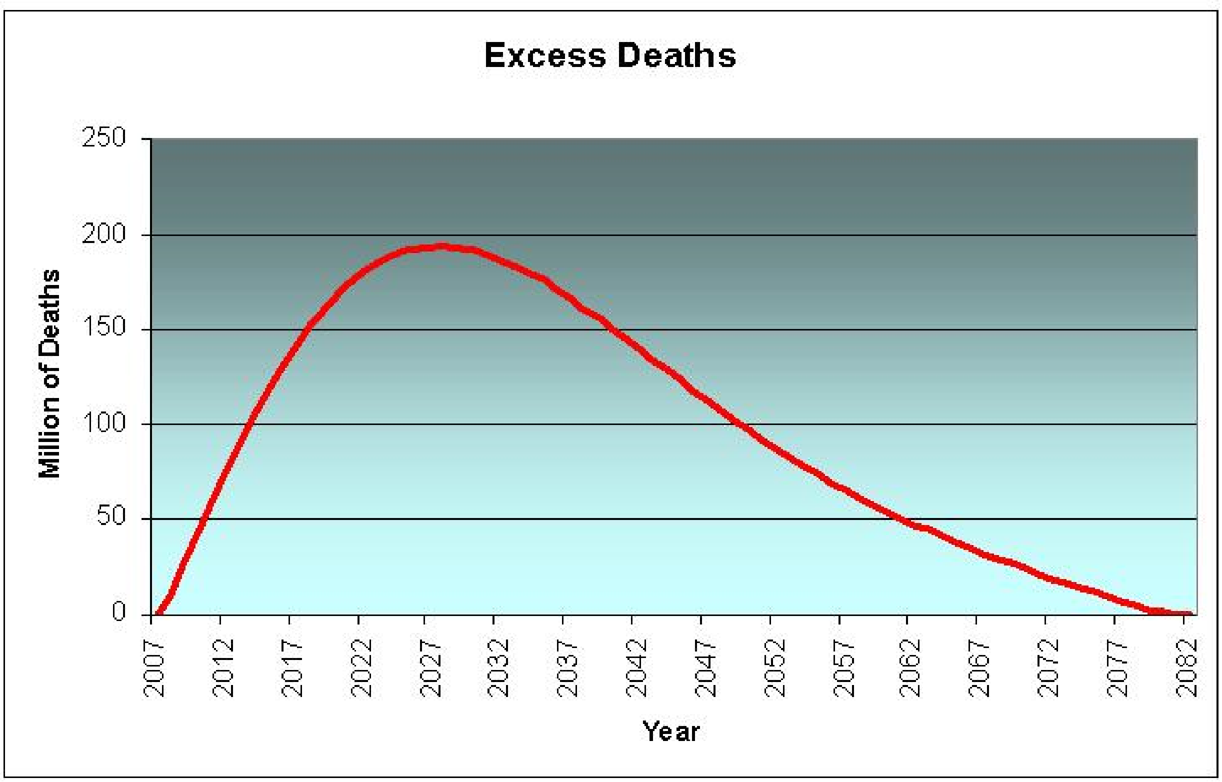


As you can see, my assumption about declining birth rates leads to a stable population, but it's still 50% larger than today. In fact, this projection is remarkably similar to the one produced by the United Nations, which estimates a global population of 9.2 billion in 2050. The message of this graph is clear. If we need to *reduce* our population, simply adjusting the birth rate is insufficient. There will be excess deaths required to reach our target.

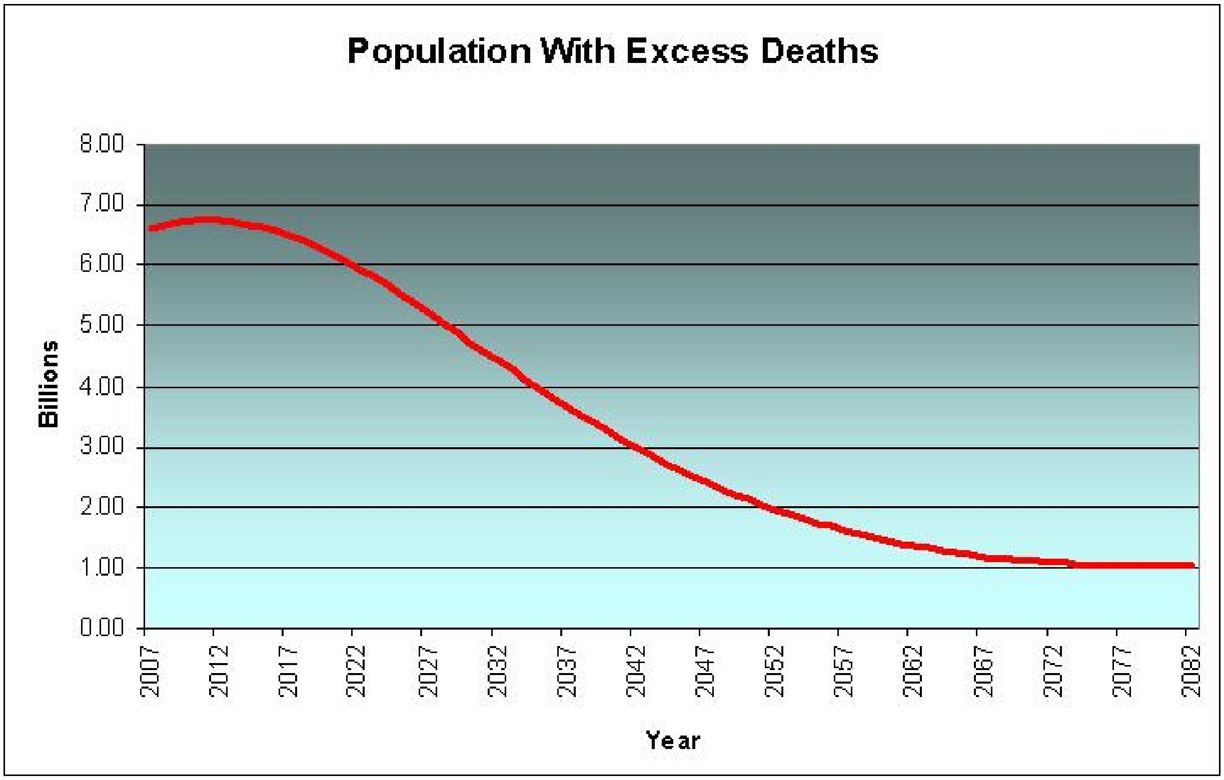
The following graph shows the excess death rate rising and then falling as described above. I will reiterate that the origin of these excess deaths is not considered in the model. It is sufficient to understand that these are not the result of old age or the various "natural causes" we have come to accept as a part of our modern life. These deaths may be due to such things as rising infant mortality rates, shorter adult life expectancies, famine, pandemics, wars etc. Some of these deaths will be from human agency, but most will not.



Applying the above excess death rate to our current population yields the following curve. As you can see, the number of excess deaths per year increases quite rapidly (consistent with the effects of overshoot) and then falls off as the population comes back into balance with the resources available. The peak rate of deaths comes much earlier than the peak in the percentage death rate shown in the above graph because the population starts to decline rapidly. A lower percentage death rate acts on a larger population to produce a higher numerical death rate. As the population declines so does the numerical death rate, even when the percentage rate still increasing.



The final graph is the outcome of the full simulation. It starts from our current population and shows the combined effects of a declining net birth rate and the excess death rate due to falling carrying capacity as described above. The goal of the model has been met: it has achieved a sustainable world population of one billion by the year 2082.



The Cost

The human cost of such an involuntary population rebalancing is, of course, horrific. Based on this model we would experience an average excess death rate of 100 million per year every year for the next 75 years to achieve our target population of one billion by 2082. The peak excess death rate would happen in about 20 years, and would be about 200 million that year. To put this in perspective, WWII caused an excess death rate of only 10 million per year for only six years.

Given this, it's not hard to see why population control is the untouchable elephant in the room - the problem we're in is simply too big for humane or even rational solutions. It's also not hard to see why some people are beginning to grasp the inevitability of a human die-off.

Conclusion

One of the common accusations leveled at those who present analyses like this is that by doing so they are advocating or hoping for the massive population reductions they describe, and are encouraging draconian and inhumane measures to achieve them. Nothing could be further from the truth. I am personally quite attached to the world I've grown up in and the people that inhabit it, as is every other population commentator I am familiar with. However, in my ecological and Peak Oil research over the last several years I have begun to see the shape of a looming catastrophe that has absolutely nothing to do with human intentions, good or ill. It is the simple product of our species' continuing growth in both numbers and ability, an exponential growth that is taking place within the finite ecological niche of the entire world. Our recent effusive growth has been fueled by the draw-down of primordial stocks of petroleum which are about to deplete while our numbers and activities continue to grow. This is a simple, obvious recipe for disaster.

This model is intended to give some clarity to that premonition of trouble. It carries no judgment about what ought to be, it merely describes what might be. The model is likewise no crystal ball. It offers no predictions and no insights into the details of what will happen. It presents the simple arithmetic consequences of one set of assumptions, albeit assumptions that I personally feel have a reasonable probability of being fulfilled.

There are factors .that will affect the course of events that have not been considered in the model. Readers may legitimately take me to task for not considering or summarily dismissing the various ways humanity is already trying to alleviate some of the foreseen dangers. For instance, my model does not mention global warming or carbon caps, and dismisses most alternative energy sources as ineffective. The model also does not address the regional differences that are bound to expand as the crisis unfolds. While such criticisms are justified and are well worth exploring in the context of oil decline, the purpose of this article is to take a high-level look at the global population situation, considering the entire planet as one ecological niche with a single aggregate carrying capacity supported by oil in its role as a facilitator of transportation and food production.

The model warns us that the involuntary decline of the human population in the aftermath of the Oil Age will not happen without overwhelming universal hardship. There are things we will be able to do as individuals to minimize the personal effects of such a decline, and we should all be deciding what those things need to be. It's never too early to prepare for a storm this big.

May, 2007