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SETTLING SPACE: IMPLICATIONS FOR POPULATION GROWTH

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We live at a critical time in the history of the Earth. The actions taken by those alive today will determine whether or not our species or any others will outlast our planet. There is now enough information available to sketch out how our population might be affected by what we do. Broadly speaking, we can choose to stay on Earth, or we can choose to settle other worlds. One choice will tie our future to the Earth; the other can lead to virtually unlimited growth.

There is a very real possibility that our civilization will not survive this century unless we make major changes to the way we live. Cheap energy has powered unprecedented, and ultimately unsustainable, population growth. This energy will soon become extremely expensive. In addition, inefficient and unwise use of resources has weakened the natural systems on which we depend for food, water, and air. Even if we met our energy needs, our waste, mostly in the form of pollution, would soon overwhelm not only us, but the world's entire food chain. If we follow our present course, the world's population could likely rise to a peak by the middle of this century and fall to a lower value than it is today, accompanied by horrors only people in our poorest countries can imagine.[1] Since our ability to travel in space depends upon an advanced technological civilization for support in its initial stages, it is unlikely, given our currently slow pace of space exploration, that the settlement of space will ever get started.

Changing how much and how well we consume resources could buy us some time. This "sustainable living" philosophy involves shifting to the primary use of renewable resources, both for energy and products. Achieving zero population growth is extremely important so that use of these resources will not increase. We must also limit waste, and render harmless the waste we have already produced. All of these steps and more may allow our population to reach a maximum that is higher than today's value and stay there, for a while. Some of what we don't need to live on can be channeled into exploring and some day establishing self-sustaining settlements on Mars, our nearest planetary neighbor with enough resources to permit it.

Some resources will also need to be devoted to protection from natural threats. Among these threats are impacts of asteroids and comets, and the onset of Earth's last ice age. Some time within a million years or so, an asteroid or comet may hit the Earth with enough energy to kill off most large animals, including us.[2] The impact threat can be mitigated by detecting, intercepting, and deflecting any such objects. The overdue ice age that follows the end of our artificial global warming will last perhaps millions of years and will require advanced technology to maintain anything like our current population. Within a few hundred thousand years, the Sun's gradual warming and the motion of the continents will conspire to ultimately kill off all plant life. After a few hundred million years, as oceans boil away, anything larger than a microbe will not be able to survive on Earth.[3] Figure 1 illustrates how the population on Earth might vary over time.[4]

Of our closest neighbors in space, the Moon may be a nice place to visit, but Mars could be a good place to live. Its proximity to asteroids, beginning with its moons, allows easy access to the huge mineral resources available there, some of which may be needed to create an Earth-like biosphere. With this terraforming, and the fact that it has the same land area as Earth, Mars may ultimately support a population rivaling that of our own planet.

Like Earth, the lifetime of a civilization on Mars will be governed by Nature and people's response to it. Being nearer the asteroids also brings a high risk of asteroid impact, so Mars will need a vigorous planetary defense system. Because of its size, Mars will be prone to lose its atmosphere, so the atmosphere will either need to be trapped (with a planet-wide dome) or replenished, perhaps with material from comets. The warming Sun may make Mars even more habitable for a while, but eventually, when the Sun becomes a red giant, Mars may be unable to sustain life.

The greatest potential for increasing the human population in the Solar System lies with the asteroids. Using material from the asteroids to build large space habitats powered by solar energy and radioactive elements suitable for nuclear reactors, over a million times the current population of the Earth could ultimately live in the Solar System.[5] This population could possibly survive until the Sun dies seven billion years from now.

To extend our collective lifetime beyond that of the Sun, we will need to have people living in other star systems. Based on a recent study of discovered planets, between 1/400 and 1/15 of the stars in our Galaxy may at some time harbor Earth-like planets.[6] These star systems would be good candidates for future settlement. Getting to them would be a major technical challenge, but we may have the capability in a few hundred years.[7]

A simple scenario for settling other star systems involves sending ships to all the nearest candidate stars. Each ship carries at least enough people to sustain population growth (about 200). After arriving, it takes some time to build the infrastructure for survival. To prepare for other trips, if desired, there must be time for growing the population enough to crew one or more ships, building other ships if needed, and acquiring enough fuel.[8] The population of each star system increases to the system's "carrying capacity," the maximum number of people who can live comfortably over the remaining lifetime of the star.[9]

The region of settled space would resemble an expanding sphere, centered on the Earth. The enclosed volume of settled worlds would grow as the cube of the radius while inside the disk of the Galaxy, then as the square of the radius until it encompasses the rest of the Galaxy. During this time, each new settled world would have fewer and fewer uninhabited worlds to choose from, mainly due to competition with other settled worlds.[10] Nearby galaxies, part of the "local group" that travels through space with us, would eventually be consumed by this expansion, if the sphere is expanding fast enough to catch up with them.[11] Figure 2 shows how the population might change during the expansion.

If we are alone in the Universe, and if we never evolve, the population of humanity could easily outlast the Sun and become much larger than any of us can imagine. If, however, there is other life in the Universe, we will have competition for resources, limiting the growth of our population. Since the time it will take to populate just our own Galaxy will be at least a million years, comparable with the present age of our entire species, it is very possible that the oldest settlements (perhaps even on Earth) may be replaced by other species descended from ours.

While the settlement of space can allow our population to become very large, the *rate* of population growth may never be as high as it is now. As demonstrated in Figure 3, the rate of growth tends to drop rapidly over time. As other galaxies such as the large Andromeda Galaxy are encountered, the rate will increase, but never higher than at the beginning of settlement.[12] This behavior is primarily due to Nature's limit on how fast we can travel.

Opening space to human exploration and settlement is considered by many to be the key to virtually unlimited population and prosperity, but it is more than that. It is the path to long-term survival.

Time is running out for our being able to take the first step, since we are already overwhelming our planet's ability to sustain our growing consumption and waste of resources.

There are several options available to us:

1. We continue on our present course, committing humanity to a minimal population, living a brutal life until natural disasters wipe us out.
2. We can collectively live within our means with a limited population, stretching our earthly resources as far as they will go. We will still be subject to natural disasters, but more of us will be living better.
3. We can set aside some resources to protect us from natural disasters, living on what's left for as long as we can.
4. We can pursue Option 3, setting aside even more resources to begin the settlement of the Solar System, starting with Mars.

Taking the last of these options will enable the settlement of the entire Solar System, and could eventually lead to the settlement of other star systems. This would optimize both the growth of our population, and the lifetime of our species (and whatever may evolve from it).

Notes

[1] This general behavior is discussed in Donella Meadows, et al, ***Limits to Growth - the 30-Year Update,*** Chelsea Green Press, White River Junction, VT, 2004.

[2] Impact projections are based on several sources, including Michael Paine, http://www1.tpgi.com.au/users/tps-seti/sta1046.htm. Note that asteroid and comet impacts, while the most frequent of the long-term threats facing Earth, are not the only ones. Nearby supernovae and gamma ray bursts may be far more lethal.

[3] Future Earth events are from Peter Ward and Donald Brownlee, ***The Life and Death of Planet Earth***, Henry Holt and Company, New York, NY, 2002.

[4] Historical data is from Robert Engelman, Population Action International, based on various written works by historians and demographers; United Nations, ***World Population Prospects: The 2002 Revision*** (New York: 2003) as quoted by Worldwatch Institute, 2004. Also: ***Time Almanac 2005***, Pearson Education, Needham, MA, 2004. Projections from 2000 to 2070 are from Dennis Meadows, World3 - 03 global simulation model as presented in Meadows, et al; the population numbers from Scenarios 1 and 2 (no change, and more resources with high pollution, respectively) and Scenario 9 (full sustainability) are used. The maximum supportable population is assumed to decrease linearly over time, along with biological productivity (see Ward and Brownlee, p. 110). Meadows, et al emphasize that their numbers represent trends, not predictions; this is the case with my projections as well.

[5] John S. Lewis, ***Mining the Sky: Untold Riches from the Asteroids, Comets, and Planets***, Addison-Wesley, Reading, MA, 1996.

[6] These numbers are used for the population projections in Figure 2, and are based on work by Charley Lineweaver and Daniel Grether from New South Wales University (as reported by Robert Roy Britt in "30 Billion Earths? New Estimate of Exoplanets in Our Galaxy," Space.com, 01/29/2002).

[7] At currently attainable speeds, it would take a few hundred thousand years to reach the nearest of these habitable worlds, and to send enough people in any reasonable fraction of a human lifetime would require hundreds of thousands of times more energy. Human (as opposed to robotic) speed records have increased at a rate of 10% per year; and if that trend were to continue, the speed of light would be reached within this century. The resources may not be available until we have access to asteroids, so we may have to wait until then.

[8] An aggressive settlement campaign might require only 30 years between arrival of one ship and departure of one or more others (this represents the "best case" for population growth). A more laid back approach could take 500 years between trips (the "worst case" for population growth).

[9] Using our one known data point, our own Solar System, this number may be between $8 \cdot 10^9$ and 10^{16} people. The lower number is from Meadows, et al, and the higher number is from Lewis.

[10] The average of uninhabited, but habitable nearby worlds would rapidly approach one.

[11] Some galaxies are moving away from us and some are moving toward us (some will even merge with ours, such as the Andromeda Galaxy). If we are going too slowly, our "sphere" may never reach all of the galaxies in the local group. Meanwhile, the Universe is expanding, moving all galaxies apart from each other.

[12] This would be the case even if we could travel at the speed of light and inhabit the space around every star. The peak growth would then be limited by how fast we could have children, and would occur soon after reaching the closest stars.

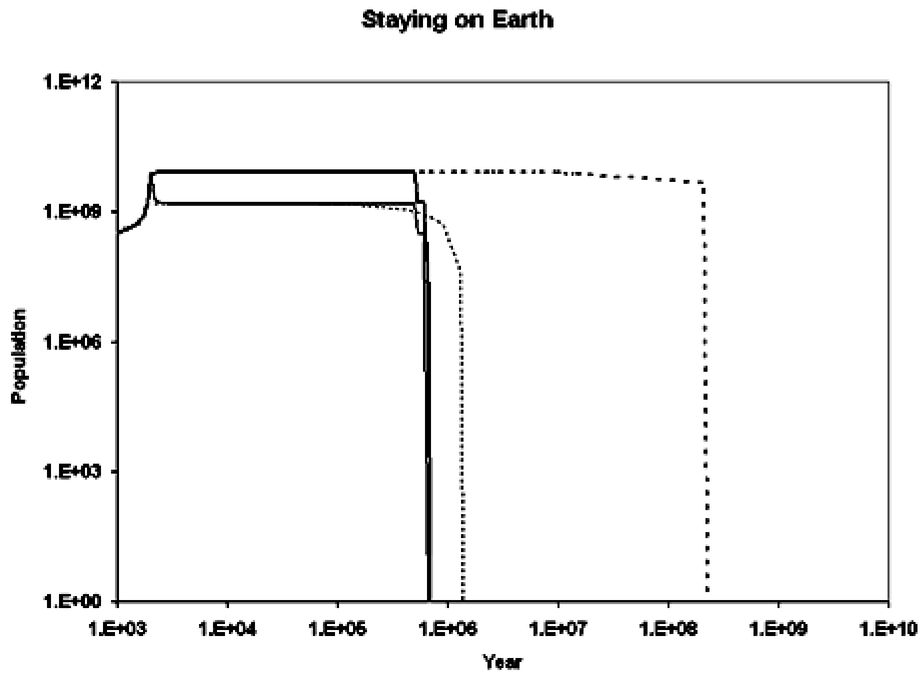

Figure 1: Worst case (solid lines) and best case (dotted lines) population projections for both business-as-usual (thin lines) and sustainable living (thick lines).

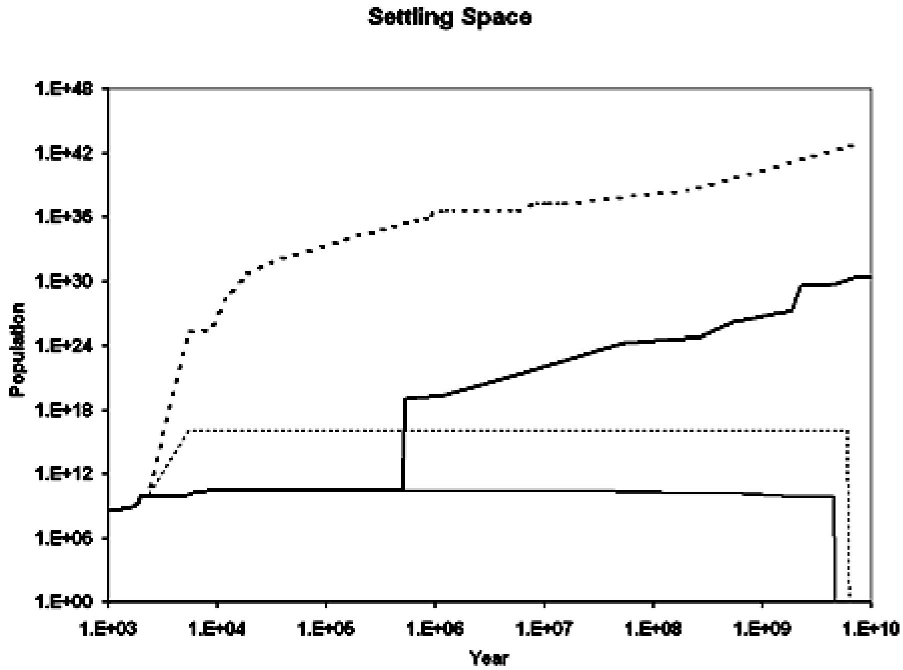

Figure 2: Worst case and best case population projections for settling the Solar System (thin lines) and other stars (thick lines). The worst case settlement of the stars assumes low speed, the fewest available worlds, low carrying capacity per system, low population growth, and a large delay between trips. The best case assumes high speed, the most available worlds, high carrying capacity per system, high population growth, and a short delay between trips. Both of the Solar System projections assume effective impact protection for Mars; without it, the worst case population would drop within a few hundred thousand years.

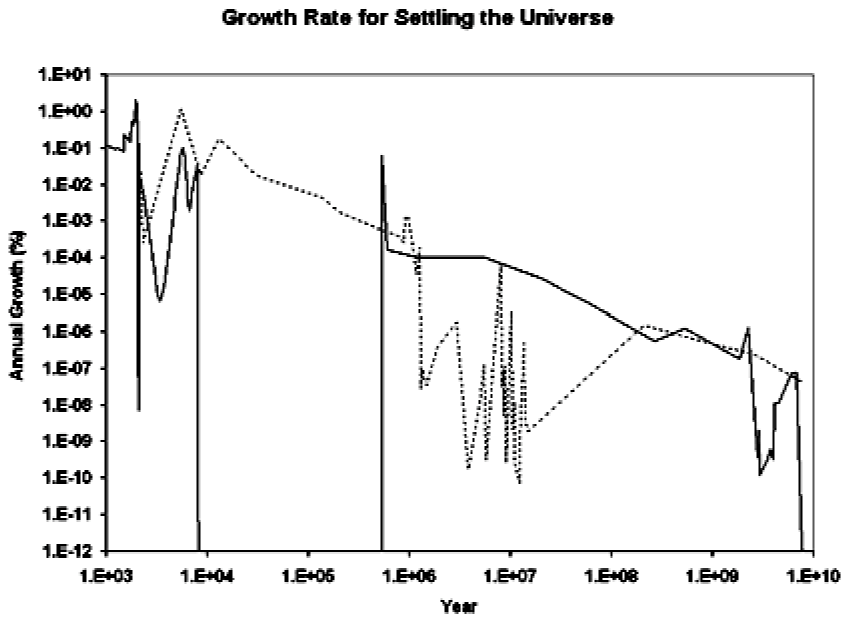

Figure 3: Projected annual growth rate of the population for settling the Universe over the remaining lifetime of the Sun. Rates tend to be roughly inversely proportional to time. Individual worlds may, however, experience a wide range of growth rates.