Population and the Settlement of Space

By Bradley Jarvis

The decisions made by those alive today will literally determine how many future people there will be, and how they will live. Here I will describe what I believe to be our main options, and sketch out how they might impact the size of the human population over the very long term.[1]

Option 1: No Change. Don't change our behavior. Early in this century, fuel and water supplies are not able to keep up with demand, pollution overwhelms us and other species, and farmland becomes useless. Our impact on the planet peaks soon and our population peaks shortly after that. The population drops to some lower level and remains low until a major natural disaster such as an asteroid or comet impact decimates us. Finding more resources may buy us a few extra years until the peak, but pollution ultimately overwhelms us and the result is the same.[2]

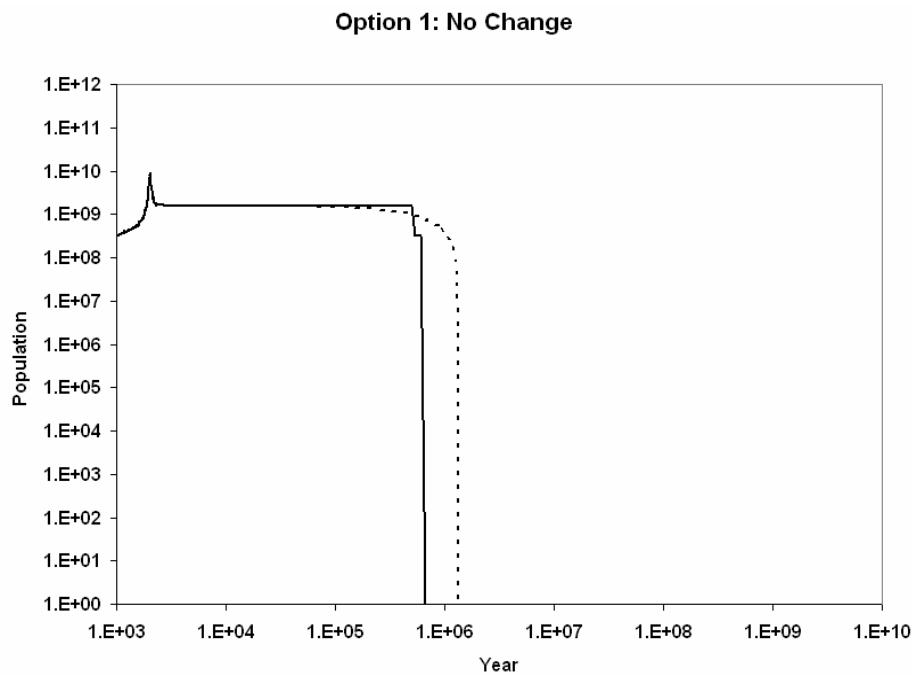

Figure 1: Worst case (solid line) and best case (dotted line) population for population over time with no change in behavior.[3]

Option 2: Sustainable Living. Reduce pollution and resource use to levels below what can be maintained with renewable resources. Population levels off, and with some technological help survives Earth's last ice age. Deflection technology may be employed to keep the population from being destroyed by comet and asteroid impacts, but ultimately plants die from CO_2 starvation, and we soon follow. Anything left is fried as the Sun heats up and the oceans boil off.

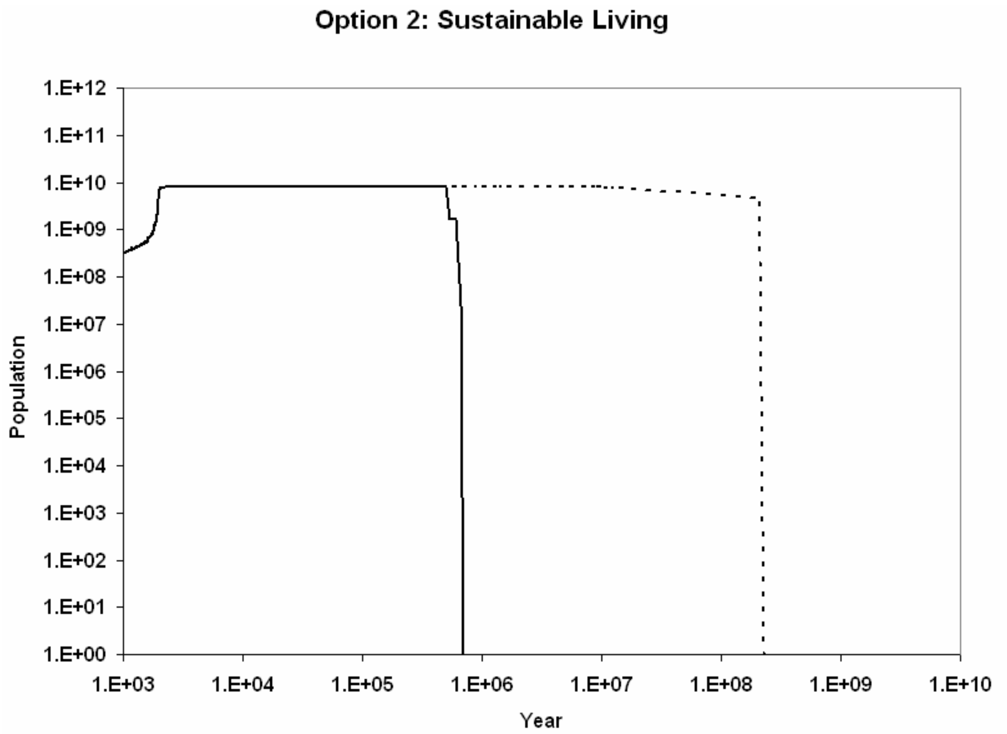

Figure 2: Worst and best case projections for population living within its means.[4]

Option 3: Settle the Solar System. While pursuing Option 2, start a self-sustaining settlement on Mars. Use terraforming to increase how many people can ultimately live there (probably no more than on Earth). Use deflection technology to remove the risk of asteroid and comet impacts. Beyond Mars, use asteroidal material to create space habitats powered by energy found in the outer Solar System. The population on Mars grows to a sustainable amount and levels off. Asteroid settlement starts some time after Mars settlement, and the asteroid population grows to a maximum and levels off. When the Sun gets too hot, Mars becomes uninhabitable; and when the Sun dies, the asteroid population dies with it.

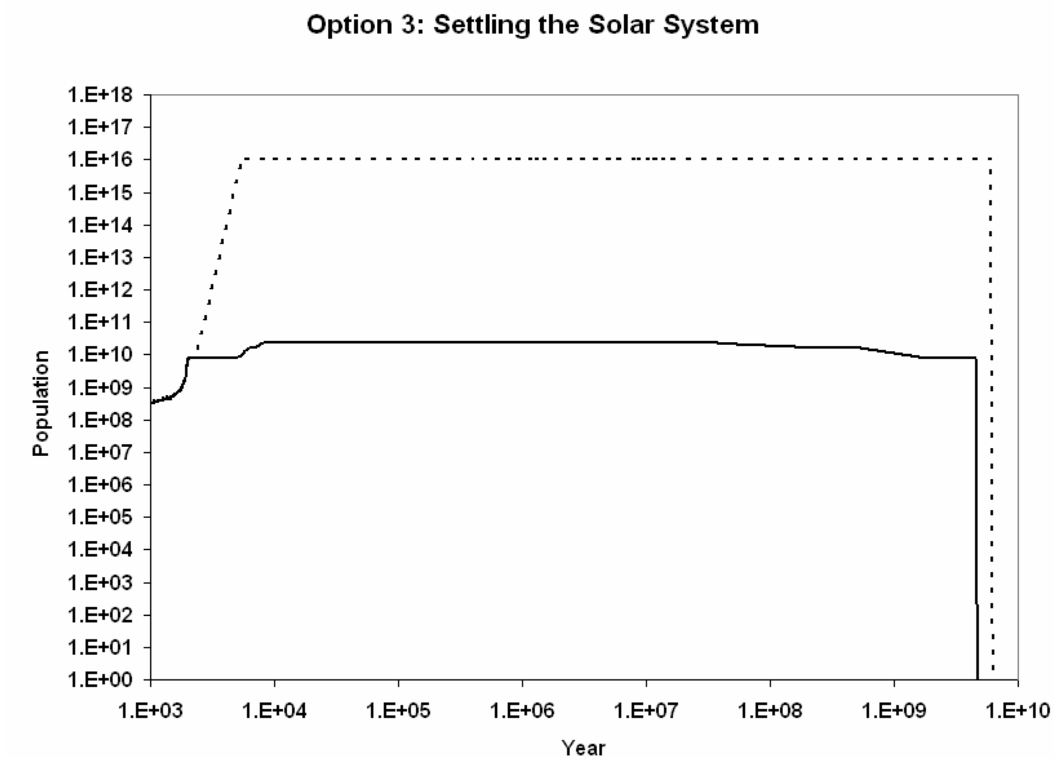

Figure 3: Population projections for settling the Solar System. The worst case (solid line) involves mostly settling Mars, with some people in the asteroids, and the best case involves fully settling both Mars and the asteroids.[5]

Option 4: Settling the Universe. While pursuing Option 3, develop the technology to travel to the stars. Only some stars will have habitable regions nearby, which may include planets, asteroids, and comets suitable for use. When the technology is developed, probably during asteroid settlement, send enough people to start self-sustaining settlements in the closest habitable regions. After some population growth and resource acquisition, the new settlements send people to other habitable regions to start their own new settlements. The population in each settled region grows to the carrying capacity of the region. While we are settling our own Galaxy, expeditions are sent to nearby galaxies, following a similar pattern. The growth of the entire population assumes the character of an expanding sphere, engulfing stars and galaxies as it encounters them. For slow speeds and scarce habitable regions, we may never escape the local group of galaxies (those moving with ours through space), and the population will reach a maximum. For high speeds and abundant habitable regions, the population continues growing until eventually the expansion of the Universe cannot be overcome.

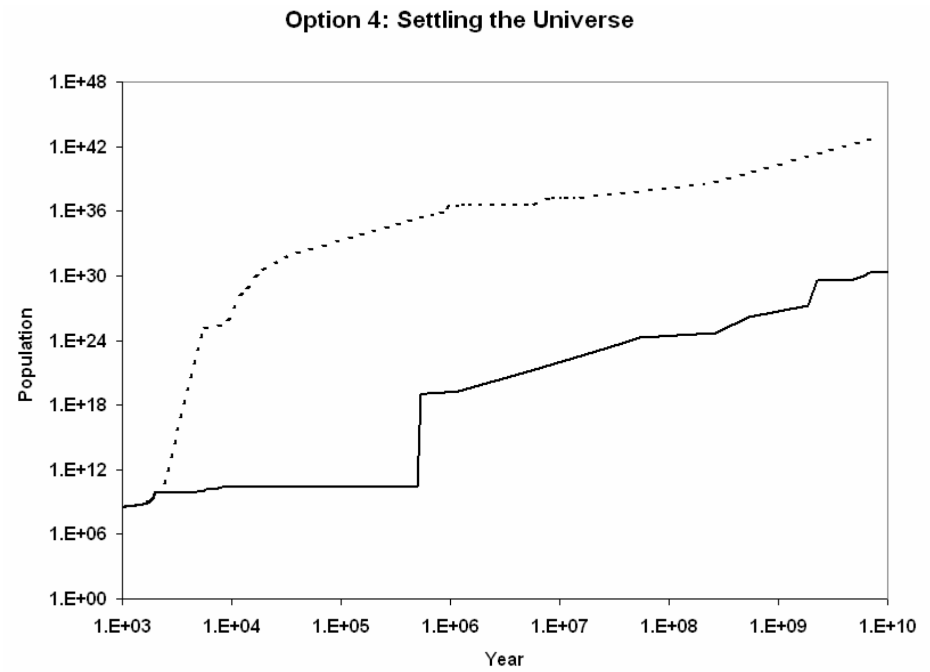

Figure 4: The worst case population trajectory (solid line) assumes no improvement in spacecraft speed, a low density of habitable regions and a delay of 500 years between each settlement attempt that follows the first one. The best case (dotted line) assumes a spacecraft speed of half the speed of light, a high density of habitable regions and a 30 year delay between attempts. The carrying capacity of each region is also a variable: In the worst case, only eight billion people can be supported (except for our Solar System, which can support 24 billion); in the best case, about a million times this many people can be supported. Note in the worst case that it takes over 500 thousand years before the first new worlds are even reached.[6]

Although the total size of the population may grow much larger than it is now, the rate of growth may never exceed its current value, and will tend to decrease rapidly over time. The maximum rate is dictated by the speed of light, which nothing can exceed, and the distribution of resources (asteroids, planets, and stars). The generally decreasing behavior of the rate is determined by the spherical nature of the expansion.

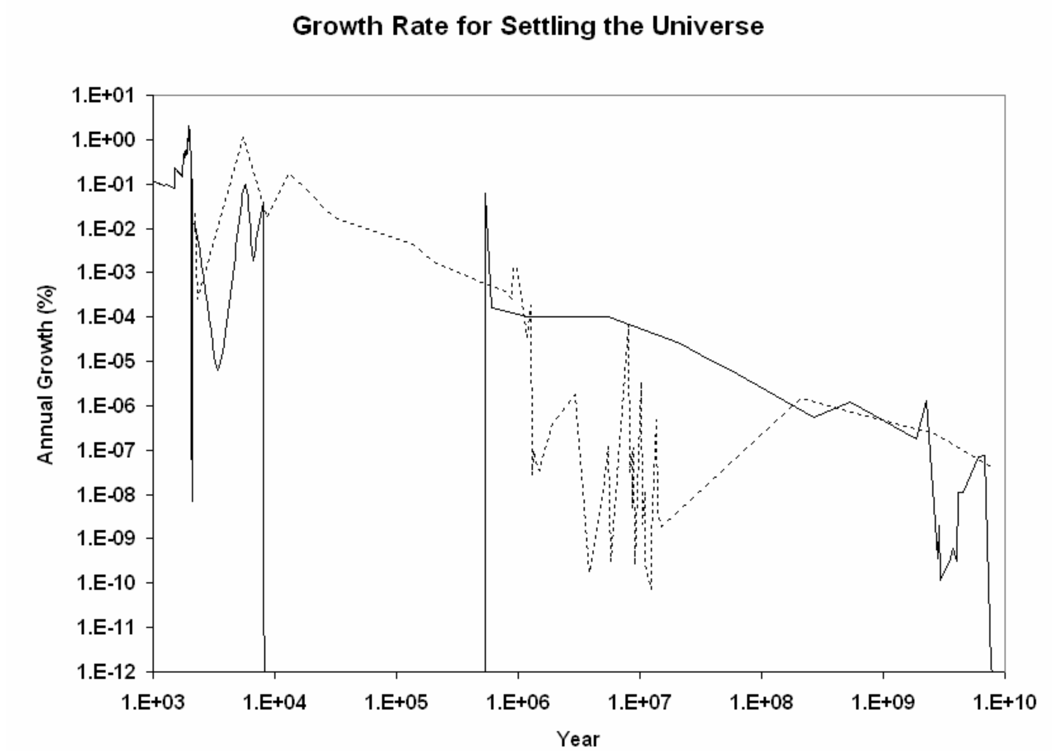

Figure 5: The worst case and best case are the same as in Figure 4. The annual growth rate for the entire population tends to be inversely proportional to time. In each case, the population will never grow as fast as it is growing now.

When considering these numbers, it is important to keep in mind several major caveats.

> All galaxies are assumed to have the same density (number per unit of volume) of stars and habitable regions as our own Galaxy. This assumption injects an uncertainty of perhaps a factor of ten to one thousand in any population numbers for other galaxies.
>
> In the best case, the time it would take to settle our Galaxy (about a million years) would be comparable to the time humans have existed as a separate species. In the worst case, this time would be roughly the current age of the Sun (over four billion years). Given these large time scales, it is possible that the overall population will gradually become a mix of human and descendant species.
>
> These estimates do not account for the possibility that there will be other life in the Universe which would be competing with us for habitable space. If there is such life, then it could limit the growth of our population.

When we compare all four options, two major features stand out.

> **Lifetime:** The lifetime of our species is shortest (less than around a million years) if we stay on Earth and have no protection from asteroid and comet impacts. With such protection, that time can be extended to 250 million years. If we settle the

Solar System, we may last between six and eight billion years, and if we settle the Universe, we will outlast the Sun altogether, with possibly open-ended growth.

Total people: The total people who may live in the future will increase dramatically if we settle space. If we do nothing new, this number (through the rest of the Sun's life) is several trillion people. Sustainable living multiplies this number by less than ten (with impact protection, the multiplier is over a thousand). If we settle the Solar System, the total number of people is more than a few hundred thousand times as much as changing nothing; and if we settle the Universe, the total is more than several trillion-trillion times as much as if we change nothing.

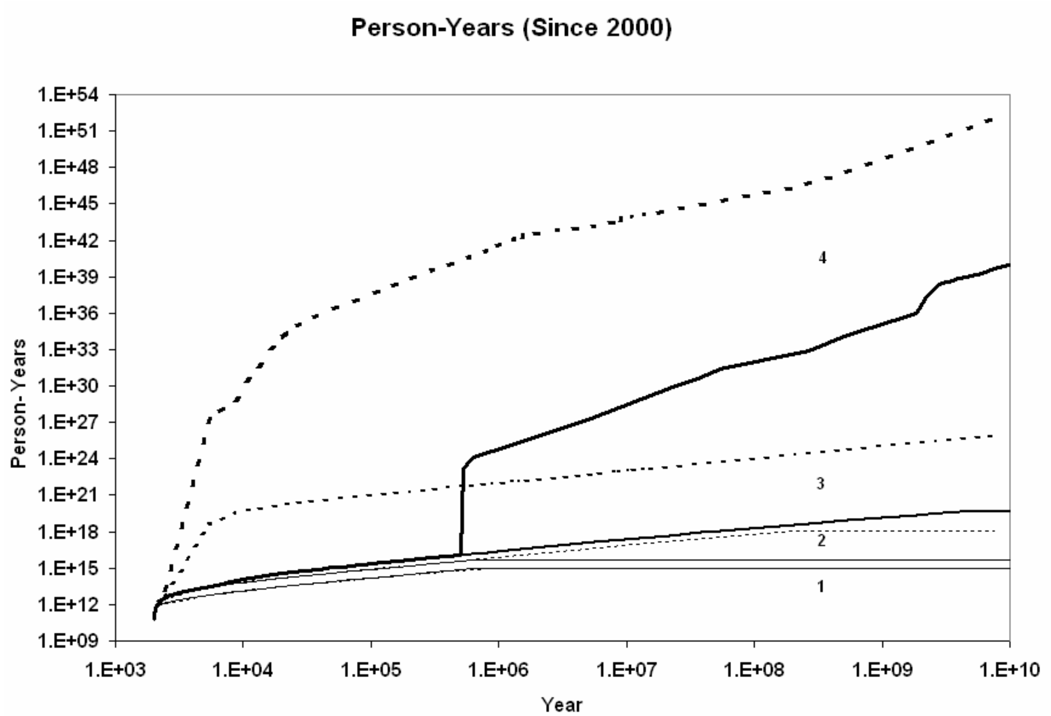

Figure 6: The area under each population curve is person-years; and is roughly proportional to the total number of people who will live at some time during a given interval. All four options are shown, with the worst case (solid line) and best case (dotted line) for each. The point that a given curve levels off marks the death of the species.

To summarize, we can do the following:

- **Change nothing** and commit to a minimal population living a brutal life.
- **Stretch our resources** on Earth with a limited population living well until natural disaster strikes. Deflect asteroids to extend that time.
- **Settle the Solar System** and have a large population until the Sun dies.

- **While settling the Solar System, develop the technology for stellar travel**, which may help us outlast the Sun.

The present generation has the power to determine whether or not our species will last more than a million years, and we must act soon. If we continue on our present path we may never again have a chance to settle the Solar System and beyond.

A highly technological society will be needed to support the initial efforts to create a self-sustaining settlement on Mars, as well as to be able to deflect threatening asteroids and comets. At our present pace of space exploration, we may not have the people and infrastructure in place on Mars before our civilization crashes. For our species to have a future of growth rather than death, the primary effort of people alive today must be to transition to a sustainable way of life while preserving our technological capabilities. Space exploration can and should continue, with the goals of having a settlement on Mars as soon as practical, and developing an asteroid and comet deflection capability (also as soon as possible, since a debilitating impact could happen at any time).

Whatever happens, we will be responsible.

Notes

[1] Both the descriptions and the associated numerical projections are crude approximations based on reasonable assumptions, and should not be construed as predictions. I have done my best to bracket the possibilities with a worst case and best case to demonstrate the uncertainties involved.

[2] This description follows from Scenarios 1 and 2 in Donella Meadows, et al, ***Limits to Growth - the 30-Year Update***, Chelsea Green Press, White River Junction, VT, 2004. It seems to represent the most common expectation among people who have studied these issues. Any doubt that we are reaching natural limits should be erased if the reader projects the current exponential growth of resource use and assumes any reasonable amount of remaining supply.

[3] Historic population numbers (here and in other figures) are 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. Numbers for 2010-2090 are from Dennis Meadows, World3 - 03 global simulation model as presented in Meadows, et al, where the worst case corresponds to Scenario 1 and the best case corresponds to Scenario 2. Impact projections are based on several sources, including www.geocities.com/dtmcbride/reference/deaths.html.

[4] Numbers for 2010-2090 are from Scenario 9 in Meadows, et al. Future Earth events (both in the figure and the description) are from Peter Ward and Donald Brownlee, ***The Life and Death of Planet Earth***, Henry Holt and Company, New York, NY, 2002. The Earth's carrying capacity is projected to decrease linearly with time based on the figure on p. 110 of Ward and Brownlee.

[5] Settlement of asteroids is described in John S. Lewis, ***Mining the Sky: Untold Riches from the Asteroids, Comets, and Planets***, Addison-Wesley, Reading, MA, 1996. Lewis estimates that 10^{16} people may be able to live in the Solar System.

[6] A speed of 25,000 mph is used for the worst case; this is the current human speed record for space travel (see http://www.astronautix.com/articles/aststics.htm). Density values vary from 0.00005 to 0.00133 worlds per cubic light year. They are derived from estimates of the number of Earth-like planets quoted in http://www.space.com/scienceastronomy/050405_earth-like.html. The carrying capacity of the Earth (from Scenario 9 in Meadows, et al) is used for the worst case of any habitable world, and I assume that both

Mars and the asteroids will carry the same amount as Earth. The best case carrying capacity for Earth and Mars is the same as the worst case, but I use Lewis' value for the asteroids, and likewise, any other star system.