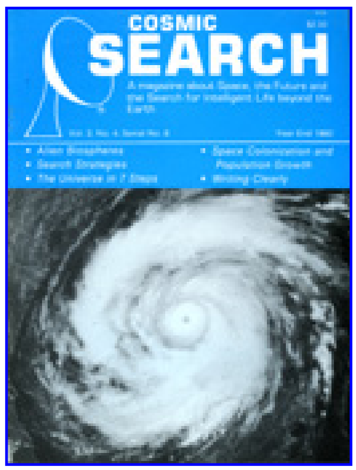
North American AstroPhysical Observatory (NAAPO)



Cosmic Search: Issue 8
(Volume 2 Number 4; Year End 1980)
[Article in magazine started on page 10]

Technical Development and Colonization as Factors in the Long-Term Variation in Limits to Growth

By: Brian A. Tinsley

It is important to distinguish between the short term limitations to growth and the long term limitations to growth. Limitations to growth involve both limitations to growth of population, and limitations to growth of the economy — meaning per capita consumption, standard of living, or quality of life. The short term limitations on both population and standard of living are the ones we hear most about, and are the ones we should be most concerned about. But the long term ones are worth examining also.

Yvon Reeder Tinsley

Brian Tinsley contemplating the perfectly fitting stonework constructed by the Incas at the Temple of the Sun at Machu Pichu, Peru. His observing trips to Peru take him over the main divide of the Andes at 5000 meters. Up there on clear June nights, with the center of tha galaxy overhead, Tinsley says it is easy to imagine soaring off into it in a new wave of colonization.

Short Term Limitations

It was pointed out by Malthus and by many others since then that population can increase very rapidly if there are no involuntary or voluntary limitations to it. The typical rate of increase of a healthy population not using birth control techniques and with an abundant supply of food is about 60 fold per century, or 4 percent per year.* (*Three generations per century of 8 children per couple is, on the average, 4 x 4 x 4 = 64.) This rapid rate of growth occurred in the USA in the early 19th century; and even greater rates are possible (my grandfather was one of 17 children). But it cannot be sustained for a long period because in 2 centuries it results in a 3000 fold increase. Without voluntary limitations the population will soon press against the resources, particularly the food supply, and there will be hunger, pestilence, and wars. Then the limitation of a higher death rate will stop the increase.

The same applies to the growth of the economy. For several decades in the 20th century the U.S. economy was growing faster than this rate of 4 percent per year when measured in terms of production and consumption of energy and material goods. We now see that economic growth at this rate cannot continue. The limitations involve using up non-renewable resources, such as oil and natural gas, non-ferrous industrial metals, precious metals, and minerals such as phosphorous compounds used as fertilizers. These non-renewable resources would actually decrease in availability even if the population and economy were stationary, but the increase of both advances the time when they will all be gone.

Other resources such as hydroelectric power, quantity of land available for cultivation, quantity of water available for industrial and domestic use, quantity of forest land for wood products and recreation, and ability of the ecosystem to deal with pollution, are constant, and cannot be expanded for an increasing population or increasing per capita consumption.

So we see that there are short term limitations to unrestrained growth of both population and per capita consumption. In fact, the exhaustion of non-renewable resources will probably force a decline of one or both before very long.

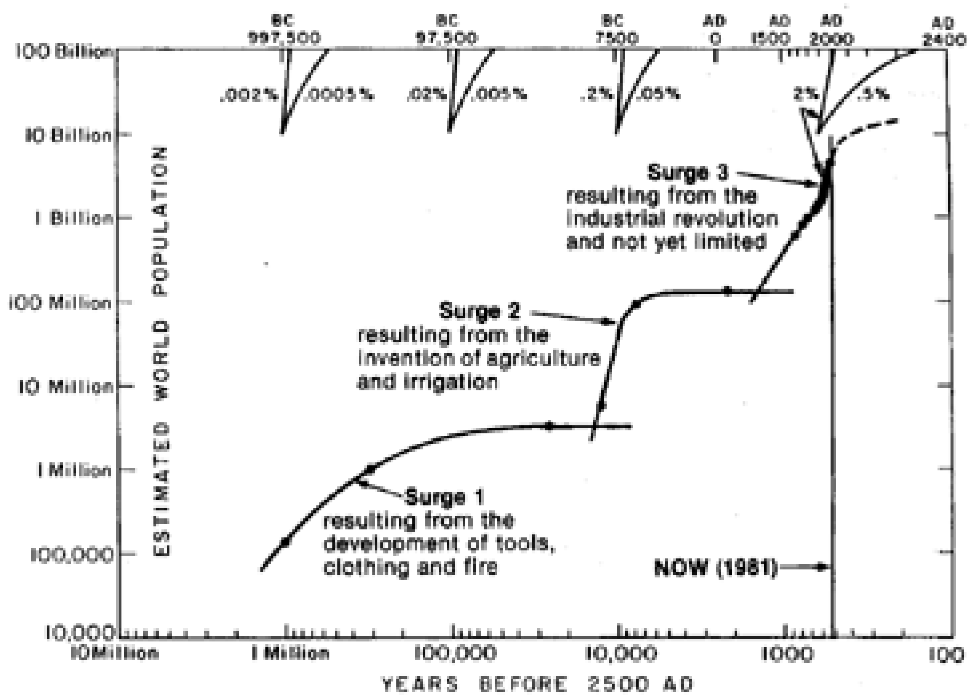
This is the short term picture, and I have been implying in my description of short term limitations that there is no fundamental change occurring in the way of life; no fundamental change in the technology that produces the food and material goods that determine the standard of living, and no colonization or emigration to essentially virgin lands or new habitats that the new technology makes possible.

Long Term Changes in the Limits

But in the long term we do have fundamental changes in technology and we do have colonization of virgin habitats. Whereas short term growth (over periods of about a century) will lead to a steady state, that steady state may change slowly (over thousands of years), as long term growth takes place. We should call the short term steady state the *quasi*-steady state.

We have had civilizations and people living in cities for 8,000 years or more, so it is relevant to wonder what the world might be like 8,000 years in the future. Will there be civilizations, and if so what sort of technology will they be based on?

The graph [below] shows the increase in world population over the last 1 million years, according to data and estimates compiled by Deevey* (*Edward S. Deevey, Jr., "The Human Population," *Scientific American*, Sept. 1960.) and updated from recent U.N. data. The percentage annual growth rate corresponding to a given slope varies with time and is illustrated at the top of the figure. The graph illustrates the effect of surges in the population growth rate followed by periods of low growth, and the extrapolation beyond AD 1980 is similarly designed. These effects will now be discussed.



Growth of the human population of the world over the last one million years. The time axis is in years before 2500 A.D., and the population and time axes are logarithmic in order to show all the data in one figure. Note the three surges in population since the time of early man. The slanting lines at the top indicate the slopes corresponding to different percentage annual growth rates. Thus, the slope of the present surge (3) is at 2 percent.

The graph shows a surge in population starting about 1 million years ago, associated with the development of tools, clothing, and fire, which allowed an advanced hunter-gather economy to develop. Our apparent ancestors, Homo Habilis, numbering perhaps 100,000 who had been living in tropical Africa., were able to support a greater population locally with this development, but more important, were able to move out into other habitats, including the fringes of the ice sheets in northern Europe and Asia, killing large mammals and using their skins for clothing.

This led eventually to populations at home in the ice of Siberia, and then Alaska, which were then able to expand south through North and South America.

About ten thousand years ago the invention of agriculture and irrigation in places such as the Middle East, China and Middle America permitted a population surge to a new level. The technological capability to cut down forests led to the development of central European population centers.

A few hundred years ago in the eighteenth and nineteenth centuries, the advent of the industrial revolution, with improved transportation, mechanization of agriculture, improved hygiene and medicine gave rise to a surge which has not yet been limited.

It is the development of technology in each case which has raised the limits of the population which the resources of the world can support. In general the technological development has raised the per capita income and consumption as well as the total population, especially where voluntary family limitation results in a population growth rate less than that of the economy.

The short term population and consumption pressure will often exhaust non-renewable resources, or resources which could be husbanded but are not. Such a situation occurred in England in the 18th century, when the consumption of wood for metallurgy resulted in the forests being cut down, resulting in a great scarcity of wood. This forced people to turn to coal (in spite of much opposition) which led to much more efficient industry that hearlded [sic; "hearlded" should be "heralded"] the industrial revolution and a surge of population growth.

Resource Substitution

The replacement of wood by coal was an example of resource substitution. Growing crops and breeding animals instead of hunting and gathering a wild population was another. But the cultures responsible for exhausting a resource do not necessarily have the social or technical capabilities for making such a substitution. The failure of the Roman civilization was partly due to the overcropping and exhaustion of the North African food growing areas without substitution.

The present short term crisis due to the depletion of non-renewable energy sources and mineral sources is likely to lead to declines of standards of living, and even population declines, *unless there is resource substitution*. Nuclear fission power and coal can provide stop-gap help for a century, but the (1,000 year) long term energy source will have to come from controlled fusion and/or solar power (photovoltaic, solar collector, or biomass conversion).

There will be large increases in the prices of heavy metals, which will probably result in very much greater recycling and much less loss. But plastic, ceramic and glass structures will have to largely replace metal. One would expect to see goods of much greater durability replacing the current variety designed for a short lifetime and rapid obsolescence.

The shortage of fertilizer (phosphorous and energetically expensive nitrogenous based fertilizer) will probably result in a shift from consumption of meat to consumption of cereals (which is a more efficient food cycle) unless biological engineering can produce new varieties of plants and animals that yield a much higher food return per unit of energy investment, or of phosphorous consumption, than at present.

The use of energy for home and office heating and cooling and for transportation will have to be reduced. This means redesigned houses with better thermal insulation — possibly in the form of compact apartments close to places of work (also better insulated) and the use of solar heating and cooling. Automobiles will have to run on fuels such as alcohol or hydrogen, produced by the biomass conversion, solar power or fusion, or from batteries, charged at night from central power plants, and they will be much smaller and energy efficient. *Unless these rather fundamental technological changes are made*, the population levels will decline, perhaps catastrophically.

With the increasing shortages and widespread pessimism, the complex structure of the economy could break down, and the food production, processing, distribution and marketing process could break down, along with water, electricity and heating oil and gas distribution. The deaths due to malnutrition and disease could amount to a significant fraction of the population. An internal or foreign war would also be likely. But it is unlikely, even with a war, that the population would go to zero. Even with 90 percent deaths in a nuclear war, population levels would be back only to levels 1,000 years ago, and with the recorded scientific knowledge and plenty of examples of its application, technology and population might soon press upwards again.

The situation at present represents a competition between the restrictive tendencies of depletion of non-renewable resources, and the growth tendencies permitted by continual technological development. At present the growth tendency due to *development is prevailing, with an annual world growth rate of 2 percent, the highest in history. In the face of severe resource depletion in the next 50 years, the situation seems inevitably about to reverse*. At least some cultures would seem to have the social and technological capabilities to take decisive action (similar to a mobilation for war) to cope with the need to substitute resources and further limit birthrates, *but much of the success of such action will depend on the seriousness with which the situation is regarded, and the willingness of people to change their lifestyles without a large amount of political friction and wasteful fighting to get the last of the resources which are bound to run out anyway*.

Colonization

Now I want to discuss the effect of colonization of new habitats. The departure from Africa of members of Homo Habilis for northern Europe and Asia a million years ago probably did not relieve short term population pressure in Africa much. But the overall effect was the development of a new center of population, very likely several times larger than the African center, and most importantly, with a higher level of technology.

Similarly the colonization of North America by Europeans, while it did not relieve population pressure in Europe much, again resulted in the development of a new center of population, comparable to that of Europe, and most importantly, it stimulated the development of new technology for new conditions.

The next step would be in the future, with the development of small self-supporting colonies in space. This seems highly speculative now, but much technological progress can be expected on a 1,000 year time scale, which is short compared to the scope of this essay. In space, solar energy would be readily available, and sufficient sources of raw materials would probably be found in asteroids and planetary satellites. The development of this type of economy would be significant, since if it was successful in being self-sustaining, then it could eventually result in units leaving the solar system under thermonuclear power, and slowly moving out to colonize the galaxy, over a period of 1 million years or so. There are about 100 billion stars in the galaxy, and there are probably planetary systems near a large fraction of them that are a source of raw materials, with the star available for energy, so in this sense the long term limits to growth would be pushed back far beyond the present ones.

The percentage annual growth rate of the total human population even with space colonization is never likely to be as large as the current rate of about 2 percent (unless almost all of the human population is wiped out and the growth starts from a low base level again). The reason is that according to the laws of physics it would be impossible for a wave of colonizing spacecraft to move out through the galaxy faster than the speed of light.* (*Assuming colonies produced a uniform population density in the galaxy, the fractional increase per unit time of volume of space populated by a wave of colonizers moving at the speed of light (c) is equal to $4\pi r^2 c/(4/3)\pi r^3 = 3c/r$ where r is the radius of the volume colonized. Thus, the fractional rate would be 2 percent per year when r equals 150 light-years, but less than 2 percent if r is greater. Furthermore, actual velocities would be well below the speed of light reducing the rate even more. Thus, it seems that the current human population increase rate is unlikely to be ever again attained. At 1 percent of the speed of light, a few million years would suffice to complete the colonization.)

Of course, it is quite possible that humans would not be the only intelligent species colonizing the galaxy in this way. In that case growth of a different sort — intellectual growth above that developed by just being in space — would very likely result from the meeting of the two cultures — even if the population and economic growth were thereby limited.

Thus, the effort to establish habitations in space should be encouraged. Even though the cost of putting man in space is significant, so was the cost to the European courts of the 15th and 16th centuries of sending Columbus (and others) out to explore the western Atlantic. We cannot expect to predict the most important benefits that would accrue from a prolonged effort in establishing man in space. Some less important ones would be a great advance in understanding the nature of the universe, of which the phenomena on earth are only an insignificant part; the tapping of new energy sources, possibly including the production and controlled feeding of miniature black holes; and a new realization of the vast range of capabilities of human beings to live satisfying lives in unconventional environments.

While we would not expect the colonization of space to have an immediate effect on the pressure of population against resources back on earth, in the long term it probably would be beneficial as new technology developed in space was applied back on earth.

This sort of transfer between colonies and parent societies has been a pattern during the last million years. Surely we owe to future generations this opportunity for future growth and development of the human species.

Relevance to Present Problems

Thus we have to realize that Malthus was right in the sense that there will always be pressure of population on resources unless there is a voluntary limitation on the population growth rate (which can be for quite private reasons, such as the preference for a life free of the burden of caring for children, or the desire to give only one or two children a better start in life than is possible for many). A generalization of *Malthus' Law* would read "The unchecked rate of natural increase of population is so high that it can only temporarily be matched by the rate of increase of the economy. In general, unless population growth is limited voluntarily, below or at the rate of increase of the economy, it will be limited by involuntary mechanisms, with a decrease in the quality of life."

In conclusion, the advancement of science has allowed us a much longer time perspective than that available to Malthus, and we see that with technological development it is possible to substitute new resources for old, and that there is no particular reason why development with a slow population growth cannot continue, *provided intelligent planning for the future is made*, and provided the investment in scientific research and technological development is continued, and further that societies are willing to plan for and accept the disruption that will inevitably accompany the change.

Yvon Reeder Tinsley

Brian Tinsley contemplating the perfectly fitting stonework constructed by the Incas at the Temple of the Sun at Machu Pichu, Peru. His observing trips to Peru take him over the main divide of the Andes at 5000 meters. Up there on clear June nights, with the center of tha galaxy overhead, Tinsley says it is easy to imagine soaring off into it in a new wave of colonization.

Brian A. Tinsley was born in New Zealand in 1937. He received his B.S. degree in 1960 and Ph.D. degree in 1963 both from the University of Canterbury, New Zealand. Dr. Tinsley has worked at the University of Texas at Dallas (originally the Southwest Center for Advanced Studies) since 1963. He teaches Physics and Astronomy and is involved in research on upper atmospheres, especially interactions between their high altitude neutral atomic coronas and trapped ions.

He currently operates photometric equipment in the Peruvian Andes; Mt. Haleakala, Hawaii; and at MacDonald Observatory, Texas, to measure optical emissions from energetic neutral atom precipitation. He is planning to make similar measurements from a spectometer on Spacelab in 1984.

HOME