

How Many Times Has the Human Population Doubled? Comparisons with Cancer

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Along with decreasing doubling times as a function of increasing rates of population growth over the past several thousand years, the human species has shown striking parallels with a malignant growth. Some cancers also display decreasing doubling times of cell proliferation during the most rapidly growing phase. At 6 billion, the number of doublings reached by the human population as of 1998 is 32.5, with the 33rd doubling (8.59 billion) expected early in the next century. In terms of total animal biomass, including that of domestic animals under human control, the 33rd doubling of human-related biomass has been passed. In terms of energy use, which is a more accurate index of the global ecological impact of humans, the human species has passed its 36th doubling. These calculations are important because, in addition to the number of doublings, the human population is showing several important similarities with a malignant organismic tumor, which results in death of the host organism at between 37 and 40 doublings. At current growth rates, the number of individual humans will reach those levels within 200-400 years from the present, but the ecological impact will be felt much sooner since the number of doublings of energy consumed will pass 37 early in the next century. These observations support the hypothesis that the human species has become a malignant process on the planet that is likely to result in the equivalent, for humans, of ecosystem death, or at least in a radical transformation of the ecosystem, the early phases of which are being observed.

INTRODUCTION

Rapid growth of the human population has resulted in doubling times as low as 35 years for the global population and 20 years in some regions (Zachariah & Vu, 1988). Doubling times of less than 20 years have been observed among some local populations (Hern, 1977, 1992). Until the past few decades, doubling times of the global population have been decreasing by 50% or more with each doubling since A.D. 0 (von Foerster et al., 1960, Von Foerster, 1966; Umpleby, 1990; Fischer 1993). Assuming a population of 250 million at A.D. 0 (Weeks, 1992, p. 29), the human population doubled 4 times from A.D. 0 to 1976, with the doubling times dropping from 1650 years (est. 500 million at 1650 A.D.) to 46 years (from 2 billion in 1930 to 4.29 billion in 1976). People who are 40 years old or more in 1998 are among the first people in history to have lived through a doubling of world population; people who are 75 years old have seen the human population triple. How many times *has* the human population doubled?

The specific event that prompted my attempt to answer this question was the astonishing comment several years ago by a careful, well-informed, and highly intelligent national political leader in a private meeting that "...we should be concerned about population growth because, after all, the human population has doubled for the first time, and this happened since the time of Christ."

After the meeting, I informed the gentleman, who was one of the highest-ranking members of the U.S. government, that the human population had doubled several times since the time of Christ and that it had doubled many times before that. Upon hearing this, he appeared startled and shaken by this news, and he asked an aide to follow up on it. Quite aside from providing accurate information to political leaders, there are compelling scientific reasons for calculating the number of times the human population has doubled.

Knowing the net number of times the human population has doubled gives us important data that are helpful in comparing human population growth to other populations and biological phenomena, in determining long-term rates of growth, in estimating the total number of human beings who have ever lived, and in estimating net increase in human biomass. We must know these things in order to understand our increasingly important role in not only occupying the planetary ecosystem, but in dominating it (Vitousek et al., 1997). An even more urgent task is to understand the dimensions and meaning of human population growth as a principal factor in ecosystem change – critical information that scientists can provide to policymakers (Brundtland, 1997). The parameters that are especially important are the present size of the population and its present rate of growth. But human parallels with a malignant process make it necessary to know the number of doublings, which are important to understanding the behavior of a cancer.

TOTAL NUMBER OF NET DOUBLINGS

In terms of the total number of population doublings, it does not really matter when we started doubling or how long the doublings have taken. But we may be reasonably sure that the first doublings, at some time lost to history, was when the number of humans, however defined, went from one to two and from two to four, and so forth. Given our mechanisms of reproduction, the impossibility of defining the “first human being” at any point in time due to the overlapping and simultaneously evolving hominid species from 3.5 to 1.5 million years ago, an actual starting point for the doubling of the human population is only a theoretical construct. At some point, we became interbreeding members of a single biological species, and we cannot determine with any precision when that occurred. In addition, there is abundant evidence that human populations waxed and waned over times, perhaps crashing to near-extinction during temporarily unfavorable climatic conditions in the late Pleistocene through early Holocene (from 100,000 through 10,000 B.P.; Harpending et al., 1993; McCorriston & Hole, 1991; Hole, 1994). McNeil (1974) documents some of the innumerable epidemics that resulted in short-term population losses of 50 to 90 percent. In the early existence of our species, the population may have doubled and halved many times before reaching any net doubling. Population growth has not been consistent or monotonic.

For the sake of examining this question and illustrating the answer, I have constructed a table based on estimates from paleontological and archeological studies, beginning with the approximate time when *Homo habilis* existed (Table 1) with $N = 1$ and ending with 1998 when the human population was estimated to have reached approximately 6.0 billion (U.S. Census Bureau, 1998).¹ Rough estimates of population growth rates are derived

from the doubling time interval estimates. The simplest mathematical answer to the question posed here is $6.0 \times 10^9 = 2^x$ where x is the number of doublings, or about 32.5

$$x = \frac{\ln(6.0 \times 10^9)}{\ln 2} = \frac{22.515}{0.693} = 32.4892 \quad (1)$$

doublings. The 32nd doubling was reached in 1976, unless we start counting with “Adam and Eve,” the point at which there were two members of the *Homo* genus, in which case the 31st doubling was reached in 1976. This is not a trivial difference, but the speculative nature of the enterprise, the difficulty of defining the first human among the various competing hominid species, and the time spans between early doublings makes this point moot and irrelevant. What matters is the number present now, and that number means that 32.5 doublings have occurred.

The simplest arithmetical way to count the number of doublings is to start with 1 and continue with a doubling until one passes the current population level (about 6 billion in 1998 and adding about 80 million net increase each year). On this basis, also, allowing for serious reporting errors and a 10% confidence interval in population estimates, we have completed 32.5 doublings from a single ancestor.

MALIGNANT PROPERTIES OF HUMAN POPULATION GROWTH

The number of doublings of the human population, the diminishing doubling times, and concomitant increasing rate of global population growth over prehistoric and historic time, are of interest because rapid growth of the human population is associated with a wide variety of phenomena disruptive of the planetary ecosystem, a matter which is of concern to some, but not all, scientists (Keyfitz, 1993). In particular, I have described the important parallels between the activity of the human species and a malignant process. The parallels are so strong and consistent that I have offered the hypothesis (diagnosis) that the human species has itself become a “malignant epiecopathologic process” engaged in converting all plant, animal, organic, and inorganic material on the planet into human biomass or its adaptive adjuncts (Hern, 1990) and that the agent of this malignant transformation is human culture (Hern, 1993).

The most direct way to support the hypothesis that the human species has become a cancer on the planet is to show that the overall characteristics of the human species, including the mathematics of population growth, have equivalence or similarity with the growth of malignant tumors.

One of the five major characteristics of a malignant process is rapid, uncontrolled growth,³ and this seems an accurate description of human population growth over the past millennia, especially during the past few centuries. This is largely due to the elimination or control of predators and competitors including those that are microbial and parasitic.

TABLE 1

Doublings of Human Population (with projections)⁵

Doubling Number	Population	Year	RONI %	Doubling Time (Years)
0	1	3,000,000 BP	0.0001	500,000
1	2	2,500,000 BP	0.0001	500,000
2	4	2,000,000 BP	0.0003	250,000
3	8	1,750,000 BP	0.0003	250,000
4	16	1,500,000 BP	0.0005	125,000
5	32	1,250,000 BP	0.0005	125,000
6	64	1,000,000 BP	0.0007	100,000
7	128	900,000 BP	0.0007	100,000
8	256	800,000 BP	0.0007	100,000
9	512	700,000 BP	0.0007	100,000
10	1,024	600,000 BP	0.0007	100,000
11	2,048	500,000 BP	0.0007	100,000
12	4,096	400,000 BP	0.0007	100,000
13	8,192	300,000 BP	0.0014	50,000
14	16,384	250,000 BP	0.0014	50,000
15	32,768	200,000 BP	0.0014	50,000
16	65,536	150,000 BP	0.0014	50,000
17	131,072	100,000 BP	0.0014	50,000
18	262,144	50,000 BP	0.0028	25,000
19	524,288	25,000 BP	0.014	5,000
20	1,048,576	20,000 BP	0.014	5,000
21	2,097,152	15,000 BP	0.028	2,500

DEVELOPMENT OF AGRICULTURE

22	4,194,304	12,500 BP	0.028		2,500
23	8,388,608	10,000 BP	0.035		2,000
24	16,777,216	8,000 BP	0.035		2,000
25	33,554,432	6,000 BP	0.035		2,000
26	67,108,864	4,000 BP	0.07		1,000
27	134,217,720	3,000 BP	0.100		700
28	268,434,000	2,000 BP	0.04	[A.D. 0]	1,650
29	536,868,000	340 BP	0.35	[1650]	200
30	1,073,736,000	140 BP	0.87	[1850]	80
31	2,147,472,000	68 BP	1.5	[1930]	46
32	4,294,944,000	22 BP	1.9	[1976]	37
32.5	6,000,000,000	0 BP	1.8		
33	8,589,888,000	15 +	1.7	[2013]	40
34	16,777,216,000	55 +	1.4	[2053]	50
35	34,359,552,000	105 +	1.0	[2103]	70
36	68,719,104,000	175 +	1.0	[2173]	70
37	137,438,208,000	245 +	1.0	[2243]	70
38	274,876,416,000	313 +	1.0	[2313]	70
39	549,752,832,000	385 +	1.0	[2383]	70
40	1,000,000,000,000	455 +		* [2453]	*

It is necessary to ask what other organism, biological phenomenon, or species population exhibits *sustained* growth coupled with extensive disruption or destruction of surrounding systems and with distant colonization.

An obvious answer is cancer, which usually becomes evident enough for diagnosis in an organism when it has 1 gm of tumor mass measuring 1 cm in diameter representing 30 doublings from a single cell and containing about 1 billion (10^9) cells (Tannock, 1989). From this point, growth to a tumor mass of 1 kg requires only 10 further doublings (ibid). Death of the host organism occurs at 37-40 doublings (1,000 billion or 10^{12}) cells (Tannock, 1992). At our current officially estimated rate of growth of numbers of people (about 1.4% per year), we would reach 37 doublings in about 200 years (1.37×10^{11} population) and 40 doublings (1.1×10^{12} population) in about 400 years.

Tannock (1989) points out that, "...the period of tumor growth that is clinically evident represents a rather short period in the total life history of a tumor." Tannock also notes that tumors do not grow because the rate of cell proliferation is faster than in normal tissues; "...they grow because the rate of cell production exceeds the rate of cell death." This is true even as the tumor approaches 40 doublings and the growth rate is diminishing due to declining cell survival. While cancer cell proliferation occurs at increasingly rapid (hyperexponential) rates in the early stages of some cancers, most cancers increase at an exponential rate, with a constant doubling time, during most of their histories (Figure 1, Slingerland & Tannock, 1998). *A declining growth rate does not mean that the cancer has stopped being a cancer.* On the contrary, it may mean that the point has been reached in the growth curve when it levels out, which occurs as the malignancy approaches the last few doublings (Figure 2, Slingerland & Tannock, 1998).

In 1960, von Foerster et al. (1960), published a formula that described the growth of the human population that was derived from a least-squares regression analysis of doubling times of the human population. With a confidence interval of ± 5.5 years, the authors found that the doubling times approached zero at A.D. 2026.87. Von Foerster's formula, originally derived to describe a pattern of hyperexponential (i.e. faster than exponential) growth in cancer cells, is given in the general form of

$$N = K/(t_0 - t)^k \quad (2)$$

where N is the number of elements, or population in billions, K, k, and t_0 are characteristic constants derived, in this case, by observation of actual historical human population size. The simplified equation has the final form

$$N \text{ in billions} = 180/2027-t \quad (3)$$

where t is the actual year of historical time in question. For the year 1993, for example, this calculation yields an estimated world population of 5.294 billion, whereas the actual number is approximately 5.526 billion according to the most recent estimates (U.S. Census Bureau, 1998). For the year 1994, the calculation yields an estimated world population of

5.455 billion, whereas the actual number observed was approximately 5.607 billion according to the most recent estimates (U.S. Census Bureau, 1998). Recent estimates of the 1998 world population by the US Bureau of the Census put it at 5.93 billion, whereas von Foerster's formula predicts a population of 6.2 billion in 1998. At this point, the lines cross, with von Foerster's formula consistently predicting larger population levels than those anticipated.

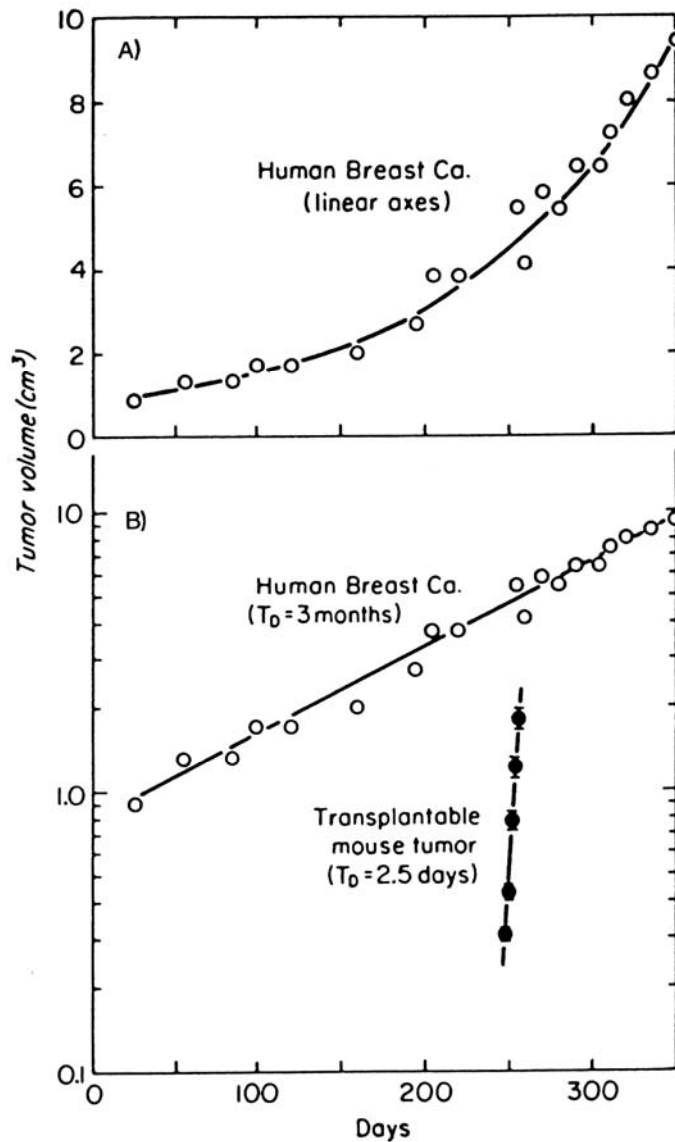


FIGURE 1. Growth curves for a lung metastasis from a human breast cancer. A, Plotted on linear axes; B, Same data plotted using a logarithmic scale for tumor volume. (Data of RP Hill and RS Bush, unpublished. Included with permission.) A growth curve for a rapidly growing transplantable tumor in a mouse is included in B for comparison. T_D = volume. [From Slingerland and Tannock (1998). Reprinted with permission of The McGraw-Hill Companies.]

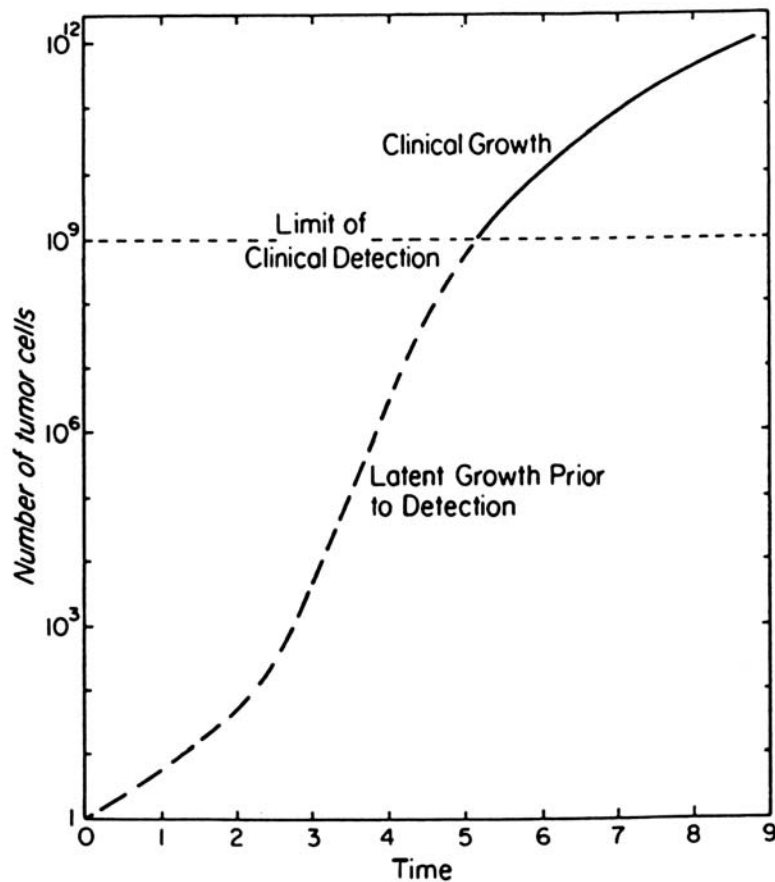


FIGURE 2. Hypothetical growth curve for a human tumor, showing the long latent period prior to detection. Tumors may show an early lag phase and progressive slowing of growth at large size. [From Slingerland and Tannock (1998).]

Von Foerster's formula, which has under-estimated world population levels since 1960 (Umpleby 1990), predicts the 40th doubling will occur at about November 13, 2026 A.D., at which time doubling times will approach zero. Emiliani has made new calculations which yield a date of around 2023 A.D. (Emiliani, 1988, p. 224). Calculations with the formula using 1994 population estimates of approximately 5.6 billion yield a projected year of this catastrophic event at 2030. Von Foerster's final equation is derived from the same general formula used for tumor growth by Tannock ($N = N_0 \exp[(K_p - K_L)t]$; 1992, p. 155), where N = number of elements at the end of time t , N_0 = number of elements at beginning of growth, K_p = rate of production of elements, K_L = rate of loss of elements, and t = time elapsed. This is not surprising since von Foerster's work laid the foundation for the formula used by Tannock. Von Foerster responded to the National Cancer Institute's request that he develop a mathematical description of the proliferation of tumor cells (von Foerster, 1959, p. 391). His application to human populations was simply a way of testing the equation (von Foerster et al., 1960).

The mathematical "singularity"⁴ described in von Foerster's paper (1966) in which doubling times approach zero ($\Delta_e \rightarrow 0$) and the population goes to infinity ($N \rightarrow \infty$) is the result of the projection of the linear decrease in human population doubling times by $\frac{1}{2}$

year per year during the past 2000 years (Figure 3). Von Foerster and his co-authors point out that in the physical sciences, a “singularity” means that the system in which it occurs experiences great instability in the vicinity of this point and is fundamentally altered in some way after this point has been passed (von Foerster et al., 1961). That point in time as calculated by von Foerster and his colleagues is less than 30 years from now.

RATES OF GROWTH OF THE HUMAN POPULATION

The point at which we begin counting and the total number of doublings are important if we wish to study any *rate* of growth of the human population. Until recently, doubling times were getting shorter as corollary of increasing rates of growth; they are inversely related. In the Paleolithic period, the doubling times were probably close to 100,000 years (Hassan, 1980). Individual lives were short and reproduction was limited by short life spans. In the Neolithic period, following the development of agriculture, there was a “population explosion,” with doubling times dropping to about 700 years or less (Bourgeois-Pichat, 1967). At that rate of growth (0.1%/year), it would take only 22,000 years to populate the planet from 1 or 2 persons to its present level of 6.0×10^9 . We may also apply today’s current global population growth rate (approximately 1.4% per year, by U.S. Census estimates) to determine that constant growth at the current rate would mean that the first human couple would have lived only about 1600 years ago. Even fundamentalists believe that Adam and Eve lived earlier than that. Quite obviously, the current high growth rates of the global population are relatively recent in the human evolutionary experience.

Various authors have pointed out that the rate of growth of the human population has steadily increased as far back as can be measured or estimated until the last few years (Pearl, 1939; Meyer, 1959; Bartlett, 1993). Von Foerster (1966) has shown that exponential growth rates described for the human population are, in fact, tangents to a hyperbolic curve on a semilogarithmic scale, indicating that the growth can be described as exponential only in the vicinity of the instant observation, and that, overall, it is hyperexponential (Figure 4). Until recently, the overall trend has been for increasing rates of increase. For example, the human population went from about 250 million at A.D. 0 to 500 million in 1650, slowed down only by the Black Death, with a doubling time of 1650 years and an average growth rate of about 0.04%, but the next doubling to 1 billion in 1850 took only 200 years with an average growth rate of 0.35% per year. The next doubling took only 80 years (2 billion in 1930), giving an average growth rate of about 1% per year, and the next doubling to 4 billion took only until about 1976 with an average growth rate of 1.5% per year.

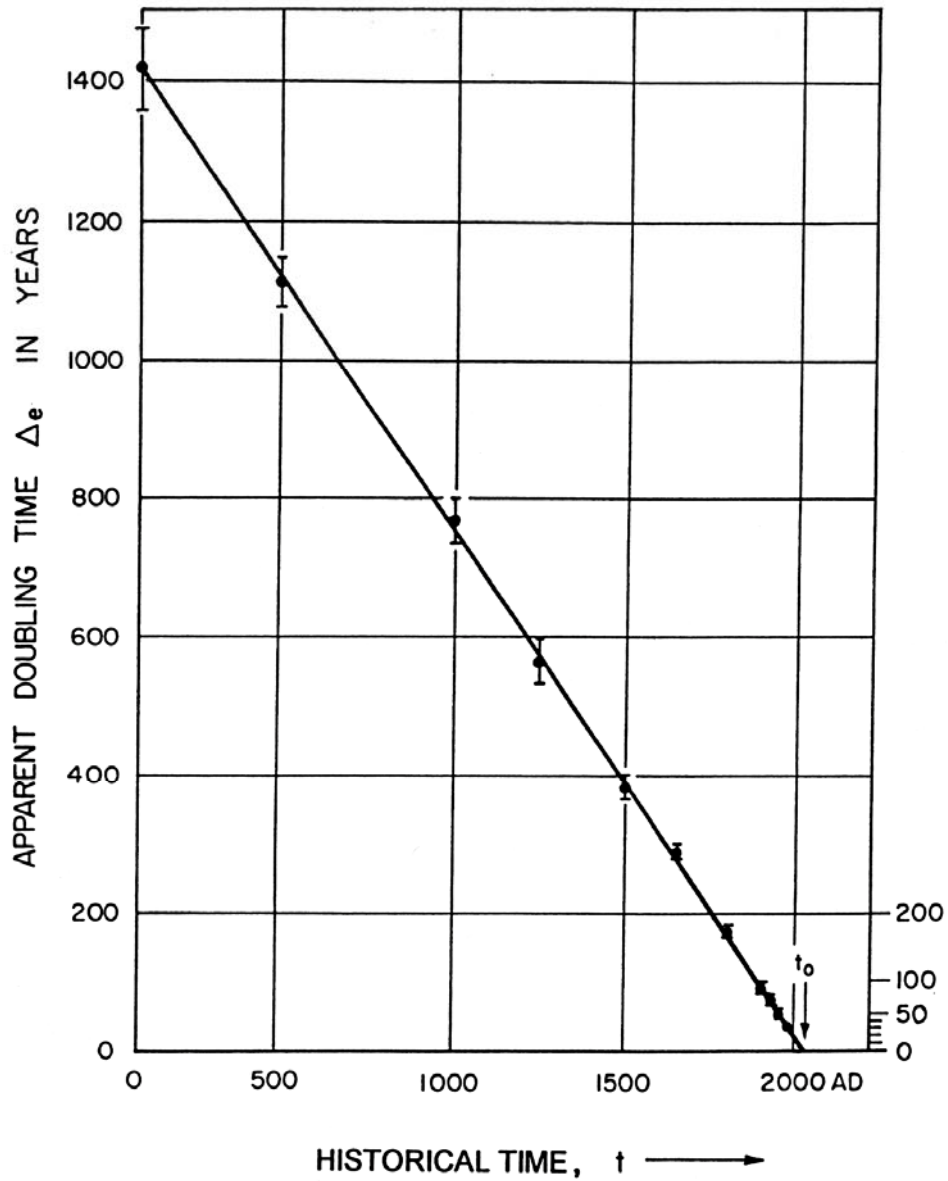


FIGURE 3. Linear-linear representation of apparent doubling times in years of the human population as a function of historical time (From von Foerster, 1966)

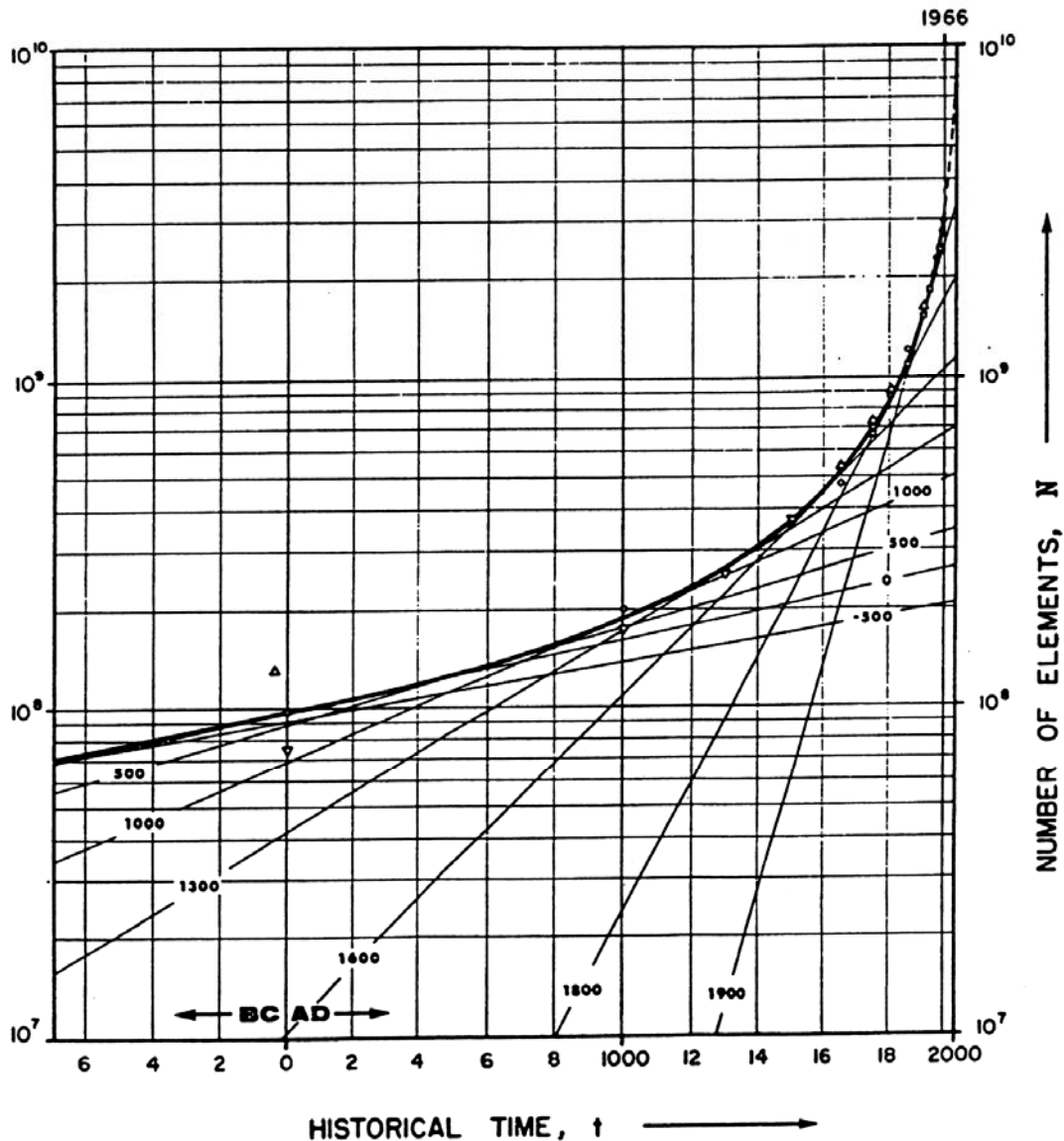


FIGURE 4. Linear-logarithmic representation of estimates of the human population N (logarithmic ordinate) by various authors, and interpolated (solid curve) over the last 25 centuries (linear abscissa). Straight lines tangent to the curve at various instances in historical time as indicated (500 B.C.; 0, 500, 1000, 1300, 1600, 1800, 1900 A.D.) represent exponential growth as apparent only in the vicinity of these instances (From von Foerster, 1966)

Contrary to reports or assertions that the global human population growth rates have decreased in recent years, there is evidence that the rate may be about 1.8% or more. For example, the global human population doubled between 1950 and 1987, going from 2.5 to 5.0 billion (37 years); it doubled between 1956 and 1994 from 2.8 to 5.6 billion (38 years); and it will have doubled between 1960 and 1998 from 3.0 to 6.0 billion (38 years). These intervals all yield a 1.8 – 1.9% rate of growth ($69.3/37 = 1.87\%$). These 37- and 38- year averages are insensitive to short-term variations, such as dramatic recent declines in local or regional fertility rates (Bongaarts, 1993, 1994), but they are at least as reliable as official estimates of current growth rates, which often exclude the most rapidly growing

marginal populations from census. Current estimates have frequently proven to be erroneously low. Umpleby (1990), for example, points out that official demographic projections (such as from the United Nations) are based on beliefs about declining future growth rates, with the result that underestimates are constantly revised upwards. The artificially narrowed differences are thus the basis for new erroneously low projections. It is indisputable, however, that the average growth rates for these two periods were at least 1.8% per year.

One of the sources of errors in official estimates is that some of the highest fertility in developing countries is occurring outside the scope of official census observations (Hern, 1977), an observation made by Pearl in 1939 (1939, p. 253). This fact leads to another possible source of projected declining growth rates. An inaccurately low estimate of current population for the base at current time (T_2) is used against which to measure the difference between that and the previous population level at T_1 , which is now known to be higher than it was thought at time T_1 to be; at time T_1 , the same error was made since the population was perceived to have grown from the previous (and now accurately known) level of T_0 in X years to the (inaccurately underestimated) population at T_1 . This gives a falsely low rate of growth z , which turns out to be the same falsely low rate of growth now being estimated at time T_2 for the same reasons (United Nations, 1992; Umpleby, 1990). The demographers use an accurate number for the previous population base – since it was collected ten years ago and now we know that it was higher than we thought – and an inaccurate, falsely low estimate for the current (today's) population, giving again a falsely low official estimate of growth rate. This continually compounded error is used to project the falling growth rates for the future. It is circular reasoning, but it is enshrined as conventional and therefore indisputable wisdom.

Another illustration that draws official estimates into question is the estimate that approximately 80 million people are being added to the 1998 world population of 6.0×10^9 each year for a growth rate of 1.4%. However, if the population grew from 5.0×10^9 in 1987 to 5.6×10^9 in 1994, and to 6.0×10^9 in 1998, that is about 100 million per year net increase for an average rate of at least 1.8% per year, and the most recent estimates of 5.6×10^9 for 1994 and 6.0×10^9 in 1998 may prove to be too low.

It very well may be that growth rates have declined in the last few years from 1.9% to 1.8% or even 1.4% per year. In the long perspective, however, it is contrary to all of human history and may be based on estimates that seriously understate true population numbers. An apparent or real decline in growth rates fits conventional notions of stabilizing density-dependent logistic population growth curves such as the classical asymptotic projection first described by Raymond Pearl (Pearl, 1922, p. 248; 1924, p. 653; 1939, p. 258) and classical demographic transition theory. At the time, Pearl, in fitting a logistic curve to the available human population numbers and the growth of *Drosophila* (1922, p. 254) offered the opinion that human population growth rates were slowing down dramatically (1939, p. 254), that the total population of the world would never be double what it was in the early 1930's (2,104,800,000), and that the "colossal limit" of 2,645,500,000 population as projected by the logistic curve would not likely be

approached until the year 2100 A.D. Nonetheless, Pearl added the observation that "...The earth on and from which man must live is not an inexhaustible source of the means of living..." (1939, p. 282). Neither Pearl nor anyone else foresaw the eclipse of that figure (2.65×10^9) in 1952 and more than doubled by the end of the century.

It could be that Pearl's logistic curve showing a stabilizing population with a declining rate of growth will prove at some point in the future to be correct. But the same curve describes the declining growth rates in the terminal stages of malignant tumors. Tannock (1992) points out that tumors may grow slowly in the very early stages, and large tumors often display declining growth rates because of increasing cell death rates and declining cell production.

While skeptics question whether human population doubling times can be shorter than current global estimates, a population which I have studied in Peru since 1964 has shown an actual population doubling time of 14.2 years. The potential doubling time of a growing system, as in tumor cells, is determined by calculating the cell production rate alone (Tannock, 1992), or, in the case of human populations, the birth rate. The population I have studied, which is not particularly unique, has shown a consistent potential doubling time of 10 years or less (Hern, 1977, 1992), with birth rates of 69.3 or more per 1000 per year, which may be near the maximum fertility for a human group.

SIMILARITIES BETWEEN THE HUMAN POPULATION AND A MALIGNANT PROCESS

The five major characteristics of a malignant tumor are: 1) rapid, uncontrolled growth; 2) invasion and destruction of adjacent normal tissues; 3) metastasis, or distant colonization; 4) de-differentiation, or loss of distinctiveness in individual cells and tissues; and 5) production of toxic metabolites. The development and mediation of the first four characteristics in human society by human culture is described in two previous publications (Hern, 1990, 1993).

In a malignant tumor, the presence of at least two of the first four major characteristics establishes a diagnosis of cancer; the human species displays all four. Elimination of two of these characteristics, including halting population growth, would not change the diagnosis.

We see now that there are other parallels with a malignant process:

- In a cancer, the rate of cell production exceeds the rate of cell death, and the rate of tumor growth may briefly become hyperexponential (an increasing rate of increase), a characteristic displayed by the human species until recently;
- The rate of world population growth may be declining, partly due to declining birth rates in some populations. However, while this is reassuring for some, it has a parallel with large malignant tumors, which also experience a diminished growth rate in the terminal phases. In a tumor, the cell death rate begins to exceed cell production rate because the tumor's metabolic needs exceed the diminishing capacity of the host organism. In humans, increasing death rates

could plausibly reflect an aging population, increasing levels of pollution, declining nutrition, and a global atmosphere diminishingly suitable for human life.

Most malignant tumors display exponential growth rates with constant tumor volume doubling times and declining growth rates in the terminal stages. Until recently, the human population has shown increasing (hyperexponential) growth rates. In spite of overall decreases in growth rates, the “growth factor” of the human population continues to display exceedingly high rates of growth. U.S. Census Bureau (1998) world population estimates indicate an overall population growth rate of 1.4% and a rate of 0.1% in developed countries, but over one-half of the population has a rate of population growth of 2.0% and a population doubling time of 35 years. A little arithmetic shows that the doubling time of the most quickly growing population will get us to 8.6 billion, the 33rd doubling of the human population, long before 2035 A.D., when it is projected to occur by the U.S. Census Bureau. This milestone appears to be scheduled to occur not much later than 2013 or 2015 A.D.

PARALLEL INCREASES IN HUMAN BIOMASS AND HUMAN-RELATED BIOMASS

The numbers of humans, including the number of population doublings, may not fully convey the ecological consequences of human population growth. Another way is to calculate the ecological impact of human population growth by determining the mass of the humans who are living in the ecosystem at any time. Human biomass increases may be calculated by taking some median numbers such as median adult mass, male and female, and median masses for children. Using an early Pleistocene estimate of 55 kg for the average adult male and 45 kg for the average adult female (Relethford, 1990, p.309) and 25 kg for the average child, we start with 100 kg for the first Stone Age couple. With four surviving children not yet of reproductive age, they have doubled their biomass. The modern counterparts of the Pleistocene couple would have the masses of 75 kg (male) and 60 kg (female) with 25 kg for the average (7 year-old) child (Frisancho, 1990). Using an assumption of these masses with 60% of the average human population over time being composed of adults (50% males, 50% females) and 40% children with average masses of 25 kg, for an approximate human biomass of 3×10^{11} kg, we have reached a doubling of 31.5 in human biomass alone for the global population from the original couple. If we also include domestic animals as human animal biomass, since they are part of human occupation of the planet (Crosby, 1986; Hammond, 1992), adding approximately 1×10^{12} kg (Table 2), we have reached 33.6 doublings.

Vitousek et al., estimated in 1986 that the human species is using 40% of all terrestrial net primary production (TNPP) on the planet. In 1997, Vitousek and his co-authors estimated that up to 50% of the land surface area of the Earth is used by human beings in some manner, that humans are using up to 50% of the accessible fresh water resources, that humans cause about 50% of all terrestrial nitrogen fixation, and that 66% of all fisheries are overexploited, depleted, or at the limit of exploitation (Vitousek et al., 1997).

There is already a serious deficiency or decline in nutrition for some groups. By the time we reach the 40th doubling, human nutrition will either be sub-marginal, as it already is for many people, or autotrophic (cannibalism).

TABLE 2

Estimation of Domestic Animal Biomass

<i>Animal</i>	<i>#</i>	<i>Av. Wt.</i>	<i>Biomass (kg)</i>
Cattle	1,271,279 x 10 ⁹	1,150 lb	663,149,950,000
Sheep & goats	1,716,749 x 10 ⁹	100 lb	77,871,734,000
Pigs	.845,108 x 10 ⁹	250 lb	95,835,247,000
Horses	.118,302 x 10 ⁹	1,000 lb	53,797,867,000
Buffalo & Camels	.157,967 x 10 ⁹	1,000 lb	71,653,831,000
Chickens, ducks, turkeys	11.5 x 10 ⁹	5 lb	26,082,000,000
Catfish	.385 x 10 ⁹	1 lb	174,636,000
Total domestic animal biomass, kg*			988,656,250,000

* Does not include domestic pets, small food animals, zoo animals. For purposes of this paper, the number used will be 1×10^{12} kg.

Sources: U.S. Department of Agriculture, Inventory And Average Liveweight, 1993, U.S., mimeo; WinRock International Reports, Little Rock, Arkansas, and World Resources 1992-1993 (Hammond, 1992)

PARALLEL INCREASES IN HUMAN ENERGY CONSUMPTION

Increases in human numbers and in human animal biomass (including domestic animals) are significant. But the global ecological impact of human activity is more accurately measured by the consumption of energy. Few things modify ecological systems as much as the use of energy for human exploitation of the environment including the extraction of minerals, the use of materials such as fossil fuels, the cultivation of food crops and other plants, and the production of greenhouse gases.

While individual caloric needs vary according to activity patterns, we may reasonably assume that the average Pleistocene adult individual burned about 3500 kilocalories (Kcal) per day. Our ancestors survived by scavenging, hunting, and gathering, all of which are activities that require high levels of energy.

With a conversion factor of 4 BTU per Kcal (Cook, 1976; Lindeburg, 1995; Coleman & Dewar, 1997), the rough equivalent of 3500 Kcal is $(4)(3500) = 14,000$; the first hypothetical Pleistocene human burned about $(14,000)(365) = 5.1 \times 10^6$ BTU per year or what we may call a "Pleistocene Energy Consumption Unit" (PECU).

In 1995, world consumption of energy was estimated at 3.63×10^{17} BTU per year (U.S. Dept of Energy, 1998). Dividing this number by the annual per capita energy consumption of 5.1×10^6 BTU in the early Pleistocene (one "PECU") yields a relative

world energy consumption of 7.1×10^{10} (adjusted) BTU's (or 7.1×10^{10} PECU's). Using formula (1) to estimate the number of doublings (x) of human energy use since our first ancestor, the result is

$$7.1 \times 10^{10} = 2^x \quad (4)$$

$$x = \frac{\ln(7.1 \times 10^{10})}{\ln 2} \quad (5)$$

$$x = \frac{25}{.693} = 36 \quad (6)$$

In terms of energy use by human beings, there had been 36 doublings as of 1995. Global energy use is doubling every 30 years at the rate of 2.3% per year (U.S. Dept of Energy, *ibid.*). We may expect the 37th doubling of energy use to occur in or about the year 2025 assuming there is no increase or decrease in the *rate* of increase in the consumption of energy.

COMPETING OBSERVATIONS AND HYPOTHESES

Compelling as the mathematics of human population increase may be, there are reasons to question whether the process of doubling of the population will continue to the points projected by the calculations in this paper. For example, Bongaarts (1998) projects a declining population in Europe and in the U.S. and a developed-world population equal to the present in the year 2050. The epidemic of HIV/AIDS in Africa raises concerns about a declining population in that continent, and the development of anti-biotic resistant bacteria raises the specter of other kinds of global pandemics that could seriously diminish the human population. We do not know what global warming will do to world food production or storage, or to large populations living at sea level, but the consequences of serious and rapid global warming or other anthropogenic atmospheric disturbances could be catastrophic.

Human history tells us nothing so much as the uncertainty of predictions about human population dynamics. As noted population scientists did not imagine in the early 20th century that the human population would reach the levels that it has already reached.

There are no real parallels with the human experience in the animal world. Certain life forms have grown in population and even gained a certain dominance for periods of time, but population eruptions in nature tend to be limited by food supply and other environmental constraints (MacLulich, 1937; Andrewartha & Birch, 1954). Serious outbreaks of highly destructive species that diminish the numbers of other species and disrupt ecosystems are almost always the result of human intervention and are more illustrations of the hypothesis of the human species as a malignant process than contrasting or comparative examples (Ehrlich & Roughgarden, 1987). Humans are the only species that possess cultural adaptations that make the environmental alterations

pervasive and permanent and which have a record of directly causing the extinction of other species.

It is possible that the numbers of the human species will stop growing completely or that the growth rate will suddenly drop to extremely small Pleistocene levels as the result of deliberate social decisions or density-dependent mechanisms prior to general ecosystem failure. It is possible that nations with relatively low population densities, abundant natural resources, and low rates of growth will be spared the global consequences of human-induced global warming, access to cheap energy, and the effects of rapid population growth in other parts of the world. But it doesn't seem very likely.

CONCLUSION

The close parallels between the total number of doublings of the human population in terms of numbers, biomass, and energy use accompanied by increasing rates of growth and the characteristics of a malignant process raise disturbing questions about the relationship between the human population and the global environment. First, it supports the hypothesis (diagnosis) that the human species has become a malignant process on the planet. Second, because of the fact that we are very close to the number of doublings at which a malignant process reaches its maximum lethal potential, we are forced to contemplate the fact that a malignancy in an individual organism continues until the host organism has ceased to function – it dies.

Humans can kill neither the Earth nor the global ecosystem. But we can modify the ecosystem in which we live to the point that it will no longer support us or other complex forms of life. Whether this point is ever reached, or whether it is reached before the human population has doubled as many times as a malignant tumor at the time of host organism death, remains to be seen.

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ENDNOTES

1. The United Nations Population Fund (UNPF) has set October 12, 1999 for commemoration of the "Day of 6 Billion." Whether one accepts the earlier estimates by the U.S. Census Bureau of reaching 6 billion in 1998, as many do, or a later commemorative date is irrelevant to the conclusions of this paper.

2. The term “epiecopathological process” is one I have coined to describe a “pathologic” process (disease state) that is operating upon (“epi-”) the ecosystem (“eco-”); all roots in the word have a Greek origin. See Liddell and Scott’s *Greek-English Lexicon* (1958) London: Oxford/Clarendon Press.
3. The five are: 1) rapid, uncontrolled growth; 2) invasion and destruction of adjacent normal tissues; 3) metastasis, or distant colonization; 4) de-differentiation, or loss of distinctiveness in individual cells and tissues; and 5) the production or excretion of toxic metabolites. The development and mediation of these characteristics in human society by human culture is described in two previous publications (Hern, 1990, 1993).
4. “Singularity” as defined by von Foerster et al. (1961) is the condition

$$\lim_{x \rightarrow x_0} y = \infty$$

Where y = population or number of elements, x = doubling time and x_0 = zero doubling time.

5. Estimates of doubling times and rates of population growth prior to 2,000 years B.P. are based on the studies and reports of anthropological demographers and paleodemographers such as Hassan, Bourgeois-Pichat, and others. Any projection offered here for the years beyond 2013 is pure speculation, but I have attempted to base my estimates on current data and likely patterns for the sake of giving the reader a thoughtful framework for the long perspective and for the possibilities for the future.

REFERENCES

- Andrewartha, H.G. and Birch, L.C. (1954). Seasonal changes in a population of adult thrips living on rose bushes. *The Distribution and Abundance of Animals*. Chicago: University of Chicago Press.
- Bartlett, A.A. (1993). The arithmetic of growth: Methods of calculation. *Population and Environment*, 14(4), 359.
- Bongaarts, J. (1993). *The fertility impact of family planning programs* (Working Papers No. 47). New York: The Population Council.
- Bongaarts, J. (1994). Population policy options in the developing world. *Science*, 63 (5148), 771.
- Bongaarts, J. (1998). Demographic consequences of declining fertility. *Science*, 282(5388), 419.
- Bourgeois-Pichat, J. (1967). Social and biological determinants of human fertility in nonindustrial societies. *Proceedings of the American Philosophical Society*, 111, 160.
- Brundtland, G.H. (1997). The scientific underpinning of policy. *Science*, 277(5325), 457.
- Coleman, G.J. and Dewar, D. (1997). *The Addison-Wesley Science Handbook*. Don Mills, Ontario: Addison-Wesley Publishers Limited.
- Cook, E. (1976). *Man, Energy, Society*. San Francisco: W.H. Freeman.
- Crosby, A.W. (1986). *Ecological Imperialism: The Biological Expansion of Europe, 1000 – 1900*. Cambridge: Cambridge University Press.
- Edelson, E. (1991). Tracing human lineages. *Mosaic*, 22(3), 56.
- Ehrlich, P.R. and roughgarden, J. (1987). *The Science of Ecology* (pp 66-72). New York: MacMillan.
- Emiliani, C. (1988). *The Scientific Companion*. New York: John Wiley & Sons.
- Energy Information Administration (1998). *International Energy annual 1998*. Washington, DC: U.S. Department of Energy.
- Fischer, G. (1993). The population explosion: Where is it leading? *Population & Environment*, 15(2), 139.
- Frisancho, A.R. (1990). *Anthropometric Standards for the Assessment of Growth and Nutritional Status*. Ann Arbor: University of Michigan Press.
- Hammond, A.L. (Ed.). (1992). *World Resources 1992-93*. New York: oxford University Press. A Report by the World Resources Institute, United Nations Environment Programme, and the United Nations Development Programme.
- Harpending, H., Sherry, S., Rogers, A., and Stoneking, M. (1993). The genetic structure of ancient human populations. *Current Anthropology*, 34(4), 438.
- Hassan, F. (1980). The growth and regulation of human population in prehistoric times. In M.N. Cohen, R.s. Malpass, & H.G. Klein (Eds.), *Biosocial Mechanisms of Population Regulation*. New Haven: Yale University Press.
- Hern, W.M. (1977). High fertility in a Peruvian Amazon Indian village. *Human Ecology*, 5, 355.

- Hern, W.M. (1990). Why are there so many of us? Description and diagnosis of a planetary ecopathological process. *Population and Environment*, 12(1), 9.
- Hern, W.M. (1992). Polygyny and fertility among the Shipibo of the Peruvian Amazon. *Population Studies*, 46, 53.
- Hern, W.M. (1993). Is human culture carcinogenic for uncontrolled growth and ecological destruction? *BioScience*, 43(11), 768.
- Hole, F. (1994). The calibration of domestication. Presented at the American Association for the Advancement of Science, February, 1994.
- Keyfitz, N. (1993). Population alarm and demographers' calm. Paper presented at the Population Association of America annual meeting, Cincinnati, April 1993.
- Lewin, R. (1992). The biochemical route to human origins. *Mosaic*, 22(3), 46.
- Lindeburg, M.R. (1995). *Engineering Unit Conversions* (2nd ed.). Belmont, CA: Professional Publications, Inc.
- MacLulich, D.A. (1937). *Changes in the abundance of lynx and snowshoe hare* (University of Toronto Studies, Biological Series No. 43, pp 1-136).
- McCorriston, J. and Hole, F. (1991). The ecology of seasonal stress and the origins of agriculture in the Near East. *American Anthropologist* 93(1), 46.
- McNeill, W.H. (1974). *Plagues and Peoples*. Garden City: Anchor Press/Doubleday.
- Meyer, F. (1959). L'accélération de l'évolution. In *L'Encyclopedie Francaise*. Paris, Larousse 20, 20-24.1
- Pearl, R. (1922). *The Biology of Death*. Philadelphia: J.B. Lippincott.
- Pearl, R. (1924). *Studies in Human Biology*. Baltimore: Williams and Wilkins.
- Pearl, R. (1939). *The Natural History of Population*. New York: Oxford University Press.
- Relethford, J. (1990). *The Human Species*. Mountain view, California: Mayfield Publishing Company.
- Slingerland, J.M., and Tannock, I.F. (1998). Cell proliferation and cell death. In I.F. Tannock and R.P. Hill (Eds.), *The Basic Science of Oncology*. (3rd ed.). New York: McGraw-Hill, Inc.
- Stringer, C.B. (1993). New views on modern human origins. In D.T. Rasmussen (Ed.), *The Origin and Evolution of Humans and Humanness*. Boston: Jones and Bartlett.
- Stringer, C.B. and Andrews, P. (1988). Genetic and fossil evidence for the origin of modern humans. *Science*, 239, 1263.
- Tannock, I.F. (1989). Principles of cell proliferation: Cell kinetics. In V.B. DeVita, Jr., S. Hellman, & S.A. Rosenberg (Eds.), *Cancer: Principles and Practice of Oncology* (pp. 3-13). Philadelphia: J.B. Lippincott Co.
- Tannock, I.F. (1992). Cell proliferation. In I.F. Tannock and R.P. Hill (Eds.), *The Basic Science of Oncology*. (2nd ed.). New York: McGraw-Hill, Inc.
- Umpleby, S.a. (1990). The scientific revolution in demography. *Population and Environment*, 11(3), 159.
- United Nations. (1992). The 1992 revision of world population prospects. *Population Newsletter No. 54*. New York: Population Division, Department of Economic and social Development, United Nations Secretariat.
- U.S. Census Bureau. (1998, June 15). *Total Midyear Population for the World: 1950-2050*. <http://www.census.gov/ipc/www/worldpop.html>
- Vitousek, P.M., Ehrlich, P.R., Ehrlich, A.H., and Matson, P.A. (1986). Human appropriation of the products of photosynthesis. *BioScience*, 36(6), 368.
- Vitousek, P.M., Mooney, H.A., Lubchenco, J., and Melillo, J.M. (1997). Human domination of earth's ecosystems. *Science*, 277(5325), 494.
- von Foerster, H. (1959). Mathematics of cellular kinetics. In F. Stohman, Jr. (Ed.), *The Kinetics of Cellular Proliferation* (p. 391). New York: Grune & Stratton.
- von Foerster, H., Mora, P.M., and Amiot, L.W. (1960). Doomsday: Friday, 13 November, A.D. 2026. *Science*, 132(3436), 1291.
- von Foerster, H., Mora, P.M., and Amiot, L.W. (1961). Letter. *Science*, 133(3456), 936.
- von Foerster, H. (1966). *The numbers of man, past and future* (BCL Report 13.0). Urbana, Illinois: Department of Electrical Engineering, University of Illinois.
- Weeks, J.R. (1992). *Population: An Introduction to Concepts and Issues* (5th ed.). Belmont, CA: Wadsworth Publishing Co.
- Wenke, R.J. (1990). *Patterns in Prehistory* (3rd ed.). New York: Oxford University Press.
- Zacharia, K.C., and Vu, M.T. (1988). *World Population Projections: 1987-88 Edition*. Baltimore: The Johns Hopkins Press. Published for The World Bank.

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