Earth's Human Carrying Capacity

Terran Woolley

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Abstract

I will be studying human population growth and the variables that affect it to determine the maximum population that the earth can support. As humans we are not as affected by simple predator-prey and other environmental factors, but are more effected by human decisions. I will be exploring these relationships to form a model for human population growth, and to determine the carrying capacity.

1. Uncertainty

There have been many attempts to model the Earth's human population. It is a difficult task, as there are many possible variables that can have an effect on the human population. In the future will there be lots of people sharing a limited amount of resources, or will the population die off and leave a more reasonable number to support? At what point will the Earth's resources be unable to support the human population?

2. Past Behavior

The annual rate of increase of the global population grew from a an average of 0.04% per year between A.D. 1 and 1650 to a peak of 2.1% around 1965 to 1970, then down to 1.6% per year in 1995.[1] The population rate has continued to decline and is now at about 1.2%.[2] It should be noted that world population calculations are prone to problems with accuracy.

3. Predators

Humans have moved themselves to the top of the food chain. The simple predator prey logistic equation will not provide an accurate model in this case. The lions and tigers and bears have been replaced by viruses and other pathogens. We will have to explore some other methods to gain a more accurate model.

4. Resources

One approach to building a model of the Human population is to look at the resources that are available. There have been studies that have divided the earth into regions, established a maximum supportable population density in every region, multiplied that by the area of the region and summed the regions.[1] This maximum population is too static and is based on a assumed supportable population density figure that is not very accurate.

4.1. Food

Some studies have tried to focus on one assumed constraint on population size. The single factor most often selected as a constraint was food[1]. A German geographer

Albrecht Penck stated a simple formula in 1925 that has been widely used: Max. Pop.=food supply/individual food requirement.[1] The food supply however, is dependent on other factors such as usable land space to grow food, losses to pests, actual yield of harvests. We find this model to be lacking.

4.2. Water

If we use water as our one assumed restraint on population size: Max. Pop.=Water supply/individual water requirement, we will get a different model. To form a better model we can try and combine some restraints: Max. Pop.=minimum of{food supply/individual food requirement,Water supply/individual water requirement}. This is an example of the law of the minimum proposed by the German agricultural chemist Justus Freiher von Liebig (1803-1873)[1]. This law states that under steady state conditions, the population size of a species is constrained by whatever resource is in shortest supply[1]. The problem with this model is that different areas of the earth have different resources, different populations, and different requirements. So far the models we have studied are too rigid and inadequate.

5. The Logistic Equation

The logistic equation is commonly used to model population growth:

$$P' = rP(1 - P/K) \tag{1}$$

where $P = P(t)$ is the population at time t, and $K = K(t)$ is the carrying capacity of the environment.

The model will be in one of three states:

- If $P(t) > K$ then $P'(t) < 0$ and the population will decrease.

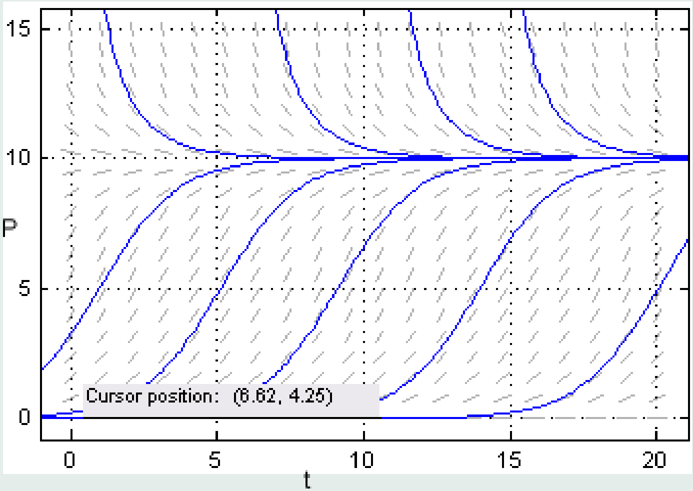

Figure 1: Graph of equation (1) with a carrying capacity of 10

- If $P(t) = K$ then $P'(t) = 0$ and the population will stay the same.
- If $P(t) < K$ then $P'(t) > 0$ and the population will increase.

This behavior can be observed in figure 1.

This model can be modified to fit the parameters of the particular system. If we fit this model to the limiting resources, we can attempt to model the Human population.

6. Building a Model

The human population size is determined by lots of different factors, not just one or two. The biggest factor effecting the human population size is the humans themselves. Our technological advances in health care and agriculture, among others, have made our population live longer and be able to support more children. As countries develop they go through a cycle of growth rate. When a nation becomes industrialized they go through a baby boom, then the rate slowly tapers off. The carrying capacity is changed by the choices that we make every day in the grocery store. We need to build a model that takes such dynamic factors into account.

6.1. Malthus

Thomas Robert Malthus (1766-1834) said in 1798,

> The happiness of a country does not depend, absolutely, upon its poverty or its riches, upon its youth or its age, upon its being thinly or fully inhabited, but upon the degree in which the yearly increase of food approaches to the yearly increase of an unrestricted population[1].

This describes a dynamic relationship between human population size and human carrying capacity. This however does not take into account the ability of humans to increase the human carrying capacity of the earth. People have constructed models in which population growth drives technological change, which permits more population growth.

Let's define $K(t)$ as the current human carrying capacity measured in numbers of individuals as a function of time, and let $P(t)$ be the total population in numbers of individuals as a function of time such that

$$\frac{dP(t)}{dt} = rP(t)[K(t) - P(t)]. \tag{2}$$

Where $r > 0$ is the Malthusian parameter. Equation (2) is called the equation of Malthus. It has a variable carrying capacity, $K(t)$ instead of the constant K as in the normal logistic equation.

6.2. Condorcet

The more people there are the more food we need. At the same time, the more people there are to get things done, build roads, farms factories, invent new technologies that increase production of food, find more sources of energy. More people may increase or decrease the carrying capacity. Suppose that the rate of change of carrying capacity is directly proportional to the rate of change in the population size.

$$\frac{dK(t)}{dt} = c\frac{dP(t)}{dt} \tag{3}$$

Equation (3) is the equation of Condorcet[1]. The Condorcet parameter c can be negative, zero, or positive. Putting equation (2) into equation (3) we produce

$$\frac{dK(t)}{dt} = c\{rP(t)[K(t) - P(t)]\} \tag{4}$$

When $c > 1$, $K(t)$ is increasing faster than $P(t)$. That means that each human is increasing the carrying capacity enough for themselves plus more. In this scenario

$K(t) - P(t)$ will always be positive for $K(0) > P(0) > 0$ and therefore $P(t)$ increases with time and grows faster than exponentially and will eventually explode to infinity. This assumes, however that the resources that we have to draw from are limitless.

When $c = 1$, $K(t)$ is increasing at the same rate as the population. So each human is adding to the carrying capacity just enough for what they consume. Then $K(t)-P(t) = K(0) - P(0)$ for any t and $P(t)$ grows exponentially.

If $0 < c < 1$ then each person adds to the carrying capacity less than they consume. The population rate increases faster than the carrying capacity is increased. As time progresses the population will exceed the carrying capacity and $K(t) - P(t)$ will be negative. $P(t)$ will follow the standard malthus equation (2).

When $c < 0$, each person is consuming more than they are producing. The carrying capacity $K(t)$ decreases, and the population will exceed the carrying capacity and $K(t)-P(t)$ will be negative. As time progresses the population will exceed the carrying capacity and $K(t) - P(t)$ will be negative. The population will die off.

The Malthus-Condorcet model combines the exponential growth model of Euler in the 18th century, the logistic growth model of Verhulst in the 19th century, and the doomsday (faster than exponential) growth model of von Foerster et al. in the 20th[1]. This model gives us a better idea of the system, however, we are using a constant c that assumes that everyone is increasing/decreasing the carrying capacity at the same rate. Such an assumption will bring inaccuracies to our model.

6.3. Mills

The amount that an additional person can increase $K(t)$ depends on the amount of resources available to make their hands productive. These resources are shared among more people as $P(t)$ increases. Let's let c be a variable $c(t)$ that decreases as $P(t)$ increases. Suppose there is a constant $L > 0$ so that $c(t) = L/P(t)$. Substituting for c

in equation (3) gives the Condorcet-Mills equation [1]

$$\frac{dK(t)}{dt} = \frac{L}{P(t)}\frac{dP(t)}{dt}. \tag{5}$$

Where L is the Mill parameter, named after British Philosopher John Stuart Mill(1806-1873)[1]. Equation (5) behaves similarly to equation (3), except that c is now allowed to vary over time. This takes into account the fact that not everyone will be affecting the carrying capacity by the same amount. If $c(0) = L/P(0) > 1$, then $K'(t) > P'(t)$ for all t, and $P(t)$ initially grows faster than exponentially. As $P(t)$ increases past L $c(t)$ passes through 1 and $K' = P'$ so the population has a brief period of exponential growth. When $c(t) < 1$ the population grows sigmoidally as a case of the logistic equation. This can be seen in Figure 2. It should be noted that this model does not take into account that people could divide the resources, so some groups have more resources than another, or pollution or climatic change. Both of which could have serious effects on the carrying capacity.

7. Conclusion

The problem of modeling population growth is a complex one. We have explored several ways of approaching the problem, from using a limiting resource to predict carrying capacity, like land, food, or water. The Condorcet-Mills equation seems to be a good overall model for the system. It's not without problems however, it does not describe accurately how much each person can increase or decrease the carrying capacity. The model fails to predict future behavior of the population because of this. This study makes it very clear that we need to be managing our resources and population, or we might end up running out of resources. Our individual decisions effect the earths ability to support us.

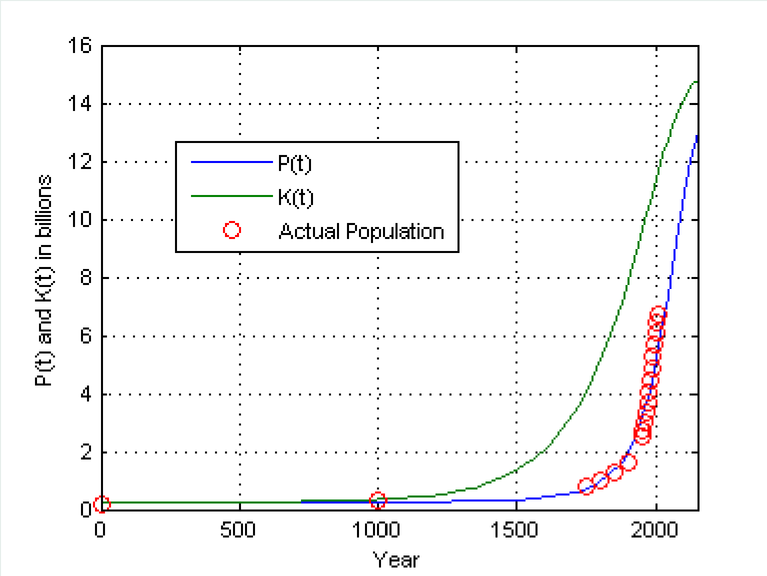

Figure 2: Graph of the solutions to equations (2)and (5) with initial conditions $P(0) = 0.2523$, $K(0) = 0.252789$, and with $r = 0.0014829$, and $L = 3.7$, compared with actual population data, all in billions.

References

[1] Cohen, Joel. *Population Growth and Earth's Human Carrying Capacity.*

[2] U.S. Census Bureau, Population Division *http://www.census.gov/ipc/www/idb/worldgrgraph.html*