

## **Conflicting Approaches to thinking about – and measuring – the impacts of humans on the planet.**

One of the questions that environmental science has been preoccupied with for a long time is the question of whether humans are overusing the planet.

As the human population passed the 6 billion mark in October of 2000, we wonder if we are “overcrowding” in some global (or local) ecological sense. Very different answers to the question emerge depending on the values and expectations that the person answering the question has. For simplicity, we identify two extremes in thinking on this question – the “doomers” and the “boomers”.

There have been a number of prominent “doomsayers”. The progenitor was Thomas Robert Malthus, an 18<sup>th</sup> and early 19<sup>th</sup> century economist, who wrote an essay on the principles of population or, A view of its past and present effects on human happiness, with an inquiry into our prospects respecting the future removal or mitigation of the evils which it occasions”

More recently, Paul Ehrlich has picked up the mantle of the doomsayers. He wrote a series of books on this theme including:

The Population Bomb (1968)

The Population Explosion (1990)

Doomsayers don’t have a very good track record. Despite more than 200 years of concern about population, we have not starved yet. Human population is larger than it has ever been and by many measures of human well being, we are doing better today – not just in the US but globally – than at any time in the past.

Are the doomsayers wrong? What do you think?

A key question is how do we know if we are overusing the planet? What sort of data would we need to answer this question? What values are embodied in this question?

At the heart of the debate between the “boomers” and the “doomers” are two conflicting world views. The boomers look at the improving quality of life. They emphasize economic and social measures and tend to focus on prices of commodities in markets. “Doomers”, in contrast, look at physical limits. They emphasize ecological, physical and health measures and argue that the relevant markets are poorly developed.

Julian Simon is the person more often associated with the “boomers”. His book “the Ultimate Resource” (1983) was an important statement of boomer philosophy. In his book, he argues that human ingenuity is the ultimate resource. A corollary of this idea is that growth in human population leads to more rapid development of new ideas, thus making scarcity less likely. They argue that as one physical resource – for example copper – becomes scarce, humans will develop alternatives – like fiber optic cables. They argue that the concept of a limiting resource may be of questionable value when applied to humans.

Ecologists tend to take a very different view. Paul Ehrlich has long argued that human population growth will eventually overwhelm the earth’s ability to supply our needs. His argument is based on the inevitability of exponential growth eventually outstripping the supply of resources.

In the mid 1980s, Ehrlich wagered against Julian Simon on whether the price of four commodity metals would go up or down between the 1980s and the 1990s. Ehrlich, pointing to growing demand, and limited supply, predicted shortage, and increased prices. Simon, pointing to human ingenuity, predicted decreasing prices as a reflection of both improved efficiency in production, and shifts in use towards cheaper alternatives. Simon won on all four metals.

Then, in 1994, Julian Simon wrote an editorial in which he claimed that human welfare is improving just about everywhere and by just about any measure. He offered to make a wager on how conditions would change between 1994 and 2004, arguing that in almost all ways, people would be better off in 2004. He offered the wagers in an editorial in the San Francisco chronicle – Paul Ehrlich’s “hometown” newspaper.

Ehrlich and Schneider made a counter offer. These two scientists offered Simon the following wagers:

### **The wagers offered by Ehrlich and Schneider in response to Simon**

1. The three years -- 2002, 2003, 2004 -- will on average be warmer than 1992, 1993 and 1994 (rapid climatic change associated with global warming could pose a major threat of increasing droughts and floods).
2. There will be more carbon dioxide in the atmosphere in 2004 than in 1994. Carbon dioxide is the most important gas driving global warming.
3. There will be more nitrous oxide in the atmosphere in 2004 than in 1994. Nitrous oxide is another greenhouse gas that is increasing because of human disruption of the nitrogen cycle.
4. The concentration of tropospheric ozone globally will be greater in 2004 than in 1994. Tropospheric ozone has important deleterious effects on human health and crop production

5. Emissions of sulfur dioxide in Asia will be significantly greater in 2004 than in 1994. Sulfur dioxide becomes sulfuric acid in the atmosphere, the principal component of acid rain, and is associated with direct damage to human health
6. There will be less fertile cropland per person in 2004 than in 1994. AS the population grows, some of Earth's best farmland is being paved over.
7. There will be less agricultural soil per person in 2004 than there was in 1994. About a quarter of the world's top soil has been lost since World War II, and erosion virtually everywhere exceeds rates of soil replacement.
8. There will be on average less rice and wheat grown per person in 2002-2004 than in 1992-94. Rice and wheat are the two most important crops consumed by people.
9. In developing nations there will be less firewood available per person in 2004 than in 1994. More than a billion people today depend on fuel wood to meet their energy needs.
10. The remaining area of tropical moist forest will be significantly smaller in 2004 than in 1994. These forests are the repositories of some of humanities most precious living resources, including the basis for many modern pharmaceuticals worldwide.
11. The oceanic fisheries harvest per person will continue its downward trend and thus in 2004 will be smaller than in 1994. Overfishing, ocean pollution and coastal wetland destruction will continue to take their toll.
12. There will be fewer plant and animal species still extant in 2004 than in 1994. Continuing habitat destruction is wiping out organisms that are the working parts of humanity's life-support systems.
13. More people will die of AIDS in 2004 than did in 1994 (as the disease takes off in Asia).
14. Between 1994 and 2004, sperm counts of human males will continue to decline and reproductive disorders to increase. Over the past 50 years there has been a roughly 40 percent decline in the count worldwide. WE bet this trend will continue because of the widespread use of hormone-disrupting synthetic organic chemical compounds.
15. The gap in wealth between the richest 10 percent of humanity and the poorest 10% will be greater in 2004 than in 1994.

So, what's the main disagreement? Do economic, social, and health outcomes miss warning signs of impending crisis? Do they underestimate the extent to which people outside the developed world already are less well off than they were a generation ago? Or are the "boomers" right?

We do know that markets are very good at altering prices for private goods – items traded in markets – but that they are very poor at setting prices for goods NOT traded in markets. Many environmental services are not traded in markets.

Thus price signals are likely to be poor indicators of current conditions. It would be relatively easy to “spend down” ecological services without having a clear economic signal.

Ecologists have reframed their concerns in a somewhat more complex manner. Rather than arguing that we are running out of food, or water, or energy the problem is seen as more general and the concern is now that we will run out of the capacity of natural ecosystems to provide ecological services to human societies. These services include waste assimilation, pollination, the removal of carbon dioxide from the atmosphere, water purification, and others.

So if we examine the recast issue – are we in danger of exhausting the earth’s capacity to the service our human societies – we are forced to ask how are so many of us managing to live so well. Are we living off the annual production of the earth system? Are we spending down the accumulated natural wealth of the past? Are we degrading the future ability of natural systems to support human societies?

There are several approaches that scientists have taken to answering these questions and we will explore each.

## **Approach #1: Carrying Capacity**

In this approach, scientists try to determine the number of animals of a particular type that an area can support. If numbers are excessive, various ecological mechanisms tend to reduce overpopulations. As the food supply is overconsumed, animals die. Also, with larger populations, there is generally increased prevalence and severity of disease, which tends to cull populations. There is also an increase in violence. Positive feedback cycles or time delays can result in damage to food supplies, which can lead to a slow or nonexistence recovery. This idea comes both from game management (Also Leopold in the essay “Thinking like a mountain” in Sand County Almanac, speaks of the tendency of elk herds to damage vegetation if populations are left unchecked) and also from equilibrium-based mathematical models of animal (or plant) populations.

### ***Logistic Growth – $Dt = r(K-N/K)$***

This is really just the two-term Taylor series expansion of a simple growth function, dressed up in new clothes

### ***Fallacy of misplaced concreteness?***

However, we simply can’t apply this concept to humans. Humans adapt to circumstances with planning and ingenuity. How then can we evaluate a “carrying capacity” in the face of economic, social, and technological change.

What do you think the human “carry capacity” of New York City is? What do you think the human “carrying capacity” of Antarctica is? Technology allows us to survive where we otherwise could not and even produce food where it would not naturally be available. Science fiction is full of examples of “technological wolds” – worlds where human life is largely unsupported by ecosystem services and human technological systems substitute for ecosystem support services.

### Approach # 2: Ehrlich’s I=PAT (1970s)

P = Population.

A = Affluence. An American child has much more impact on the world than someone from sub Saharan Africa

T= Technology. Consumption patterns aren't enough either.

Conceptual, not quantitative relationship

Better as  $I = f(P,A,T)$ , but even that is pretty fuzzy....

How do you operationalize this? What are the relevant units for discussion of overexploitation of natural systems?

### Approach # 3: Global net primary production

(Vitousek, Peter M, Paul R. Ehrlich, Anne H. Ehrlich, and Pamela Matson. 1986. Human appropriation of the products of photosynthesis. Bioscience 36(6):368-373.)

This is an interesting approach. In this approach, scientists try to calculate the percentage of primary productivity that humans appropriate both directly and indirectly. From their paper, we summarize.

| Estimate   | Percent of GLOBAL NPP | Percent AQUATIC NPP | Percent of TERRESTRIAL NPP |
|--|-----------------------|---------------------|----------------------------|
| Low<br>(Direct use of NPP for food, fodder, wood products and fisheries)   | 3.2%                  | 2.2%                | 3.9% (omits fisheries)     |
| Intermediate<br>(Cropland, managed grazing land and NPP consumed or burned on natural grazing lands, Forest plantations, harvests, and clearing, Production lost to inhabited lands) | 19.0%                 | 2.2%                | 30.7%                      |
| High<br>(adds potential production lost because of   | 24.8%                 | 2.2%                | 38.8%                      |

|   |  |  |  |
|---|--|--|--|
| human use, desertification, and land degradation) |  |  |  |
|---|--|--|--|

The overall argument is that this is a large fraction of global NPP. All non-human species and ecosystems must "run" on the remaining fraction.

### Approach 4: Ecological Footprints

Footprints are the land area that would be required to support you, at your current consumption patterns, in a sustainable manner. Footprints focus on the material and energy flow associated with human activity. They draw heavily on “back of the envelop” thinking and are very much in the spirit of the material on this site. Although detailed footprint analysis is data intensive, crude footprint analysis takes just a few assumptions. They can be generated for a person, an institution, a town, a country, or the entire population. Even if they don't answer the question – Are we destroying the earth's ability to sustain humans – they can illuminate consumption patterns in useful ways.

To see how to think through this sort of a problem, let's work through an example. What is the amount of land that it would take to support a Bates College student sustainably for one year. In the lab, we have developed a data intensive approach to answering this question. Here lets look at a back of the envelop approach.

One approach we could take is to start with the connection between economic activity and the consumption of energy. In the US, we consume roughly 11.1 million Joules per dollar of output. The average US carbon intensity of present energy mix is  $11.3 \times 10^{-6}$  moles C per joule. There are 14.49 moles C per dollar  $CO_2$  has a molecular weight of 44, so 637.45 g  $CO_2$  per dollar of economic activity.

Next we need to figure out the amount of land required to absorb this carbon dioxide. If we assume that we use forest land to sequester this carbon, then we can say that

$$637.5 \text{ g } (CO_2) / 2620 \text{ g}(CO_2)/m^2 \text{ forest} = 0.26 \text{ m}^2 \text{ of forest.}$$

This is an underestimate because a sizable fraction of NPP is remineralized rapidly – e.g. leaves.

Forests sequester about 180 g/  $m^2$  of C (from Wackernagle and Rees 1996)

$$637.5 \text{ g } (CO_2) / 180 \text{ g } (CO_2) / m^2 = 3.54 \text{ m}^2 \text{ per dollar of economic activity}$$

What is the “ecological footprint” needed to support what is, today, probably a typical students single greatest form of consumption – his or her education?

|                         |          |
|-------------------------|----------|
| Cost of a year at Bates | \$34,000 |
|-------------------------|----------|

|  |                              |
|--|------------------------------|
| Imputed Energy Use (j)                                 | 378 x 10 <sup>9</sup> joules |
| Imputed Carbon Emissions (kg)                          | 5,911 kg                     |
| Imputed Carbon Dioxide Emission (kg)                   | 21,673 kg                    |
| Related Forest Land Area<br>(Total Productivity Basis) | 0.83 ha                      |
| Related Forest Area<br>(Sequestered Carbon Basis)      | 12.04 ha                     |

What then are the assumptions associated with this calculation?

Note this does not incorporate all land use, only the land required to supply a student with the energy associated with a dollar of economic activity

Should this be adjusted to take into account the fact that Bates College Energy Use is different from the US global economy – recall we are talking not just about direct energy use, but also about indirect energy use in things like buildings and equipment?

If we look in more detail about ecological footprint calculations, we see that they have advantages and disadvantages, as well as multiple approaches to carrying them out. The footprint approach allows us to include impacts not explicitly linked with NPP and it also allows us to model how different consumption patterns or production systems might alter the footprint. This approach requires a lot of assumptions and the quality of the data available to calculate these footprints is of concern.

We leave it to you, the student, to use the data provided below to calculate the land required to support the food you eat.

### Productivity of Different land Areas

|                                  | Area<br>m <sup>2</sup> | Production<br>J | Productivity<br>j/m <sup>2</sup> | Productivity<br>g(CO <sub>2</sub> )/m <sup>2</sup> |
|----------------------------------|------------------------|-----------------|----------------------------------|--|
| Forest                           | 3.10E+13               | 1.02E+21        | 32,900,000                       | <b>2619</b>  |
| Woodland, Grassland, and Savanna | 3.70E+13               | 1.09E+21        | 29,500,000                       | 2349   |
| Deserts                          | 3.00E+13               | 6.49E+19        | 2,200,000                        | 175  |
| Arctic-Alpine                    | 2.50E+13               | 4.40E+19        | 1,800,000                        | 1439   |
| Cultivated Land                  | 1.60E+13               | 3.14E+20        | <b>19,600,000</b>                | <b>1560</b>  |
| Human Area                       | 2.00E+12               | 8.37E+18        | 4,200,000                        | 334  |
| Other Terrestrial                | 6.00E+12               | 2.24E+20        | 37,300,000                       | 2970   |
| Terrestrial Total                | 1.47E+14               | 2.77E+21        | <b>18,800,000</b>                | <b>1497</b>  |
| Lakes and Streams                | 2.00E+12               | 1.67E+19        | 8,400,000                        | 669  |
| Marine                           | 3.61E+14               | 1.92E+21        | 5,300,000                        | 422  |
|                                  | 3.63E+14               | 1.93E+21        | 5,300,000                        | 422  |

|       |          |          |           |     |
|-------|----------|----------|-----------|-----|
| Total | 5.10E+14 | 4.70E+21 | 9,200,000 | 732 |
|-------|----------|----------|-----------|-----|

Here is an outline for how you should approach this problem.

- (1) Figure out energy content of food eaten
- (2) Adjust for consumption of animal protein
- (3) Estimate net primary production to supply that food
  - a. Adjust for fraction of NPP harvested,
  - b. (should also adjust for proportion of food that is consumed by pests, decomposes or otherwise is wasted, but data on that is scarce).
- (4) Convert from NPP to land area based on estimate of productivity of Agricultural Land
  - a. Average US agricultural (grain?) productivity anyone want to guess?

## Energy in a “Typical” Diet

Energy in a typical diet, expressed in Joules per Year

|                  |             |                   |            |
|------------------|-------------|-------------------|------------|
| calories per day | Days/Yr     | calories per year | j/yr       |
| 2500000          | 365         | 912500000         | 3817991632 |
| cal/j            | J/cal       |                   |            |
| 0.239            | 4.184100418 |                   |            |

## Direct and Indirect Annual Consumption of NPP

|                              | Non-Vegetarian |                           |   |  |
|------------------------------|----------------|---------------------------|---|--|
|                              | Vegetarian     | Direct Annual Consumption | Total Direct and Indirect Consumption (conversion efficiency = 5) | Indirect, (conversion efficiency = 10) |
| Energy in Meat(J/yr)         | 0              | 2.4E+08                   | 1.2E+09   | 2.4E+09                                |
| Energy in Other Foods (J/yr) | 3.8E+09        | 3.6E+09                   | 3.6E+09   | 3.6E+09                                |
| Total Food Energy (J/yr)     | 3.8E+09        | 3.8E+09                   | 4.8E+09   | 6.0E+09                                |

## Estimate proportion of agricultural primary production that is eaten

One Way To Estimate Proportion of NPP of Agricultural Lands that is Consumable

1.7 Pg grain harvested annually

20 percent is water

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1.36 Pg biomass harvested  
 0.3 Pg non-grain foods  
 1.66 Pg OM produced on all ag lands  
 15 Pg NPP in cultivated land  
 That suggests  $1.7/15 = 0.113$   
 This is about 1/9th of NPP.  
 Figure does not include post-harvest waste, spoilage,  
 or consumption by pests.

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Data From Vitousek et al 1986.

## A Second Estimate

**USDA Agricultural Statistics Service Report 2000 wheat production**  
**62,589,000 metric tonnes Wheat Produced on 21,781 000 ha**

### Wheat Production in the US

62,589,000 metric tonnes ?  
 21,781,000 ha?  
 2.87 t/ha  
 2873.6 kg/ha

### Rough Estimate Fraction of NPP that is Yield

287.4 Agricultural Yield (g (Wheat)/m<sup>2</sup>)  
 229.8847619 Biomass Production, (80% of Yield), g(OM)/m<sup>2</sup>  
 936.3 Global Average Productivity Cultivated Lands, g (OM)/m<sup>2</sup> of  
 That's low for US wheat production  
 0.245525136 Fraction of NPP harvested (too high)

## Convert to Land Areas Based on Average Global Productivity

*Now, convert from Joules of food energy to land area*

How do you want to do that?

Calculation uses production data for cultivated lands on your hand out

Productivity = 19,600,000 joules per meter squared

|                                      | Land to Support<br>Food for a<br>Vegetarian | Land to Support Food<br>for a Carnivore who<br>Eats "Efficient" Meats | Land to Support Food<br>of a Carnivore who<br>Eats Inefficient Meats |
|--------------------------------------|---|---|--|
| Assuming all NPP is eaten by humans  | m <sup>2</sup> 194.80                       | 242.86  | 304.08   |
|                                      | Ha 0.019                                    | 0.024   | 0.030  |
|                                      | Acres 0.047                                 | 0.058   | 0.073  |
| Assuming 1/5 of production is eaten  | m <sup>2</sup> 973.98                       | 1,214.29  | 1,520.41   |
|                                      | Ha 0.097                                    | 0.121   | 0.152  |
|                                      | Acres 0.23                                  | 0.29  | 0.36   |
| Assuming 1/10 of Production is Eaten | m <sup>2</sup> 1,947.95                     | 2,428.57  | 3,040.82   |
|                                      | Ha 0.19                                     | 0.24  | 0.30   |
|                                      | Acres 0.47                                  | 0.58  | 0.73   |

from Wackernagle and Rees 1996