Your ECOLOGICAL *footprint*

How Much Net Primary Production Do You Use?

The role of humans in the global carbon cycle can be quantified by measuring the fraction of net primary production (NPP) that we use. NPP is a critical factor because it represents the total amount of biological energy available to heterotrophs. As such, the fraction of NPP consumed by humans conveys two aspects of society's ecological footprint. The finite supply of NPP implies that the fraction used by people represents the degree to which we are approaching the upper limit of the supply of biological energy. Second, as we increase our use of NPP, we reduce the amount of biological energy available to other species, which reduces the planet's ability to support these other species.

Determining the fraction of NPP consumed by humans requires two difficult calculations: the NPP generated by the entire planet and the amount used by humans. Scientists calculate NPP by combining climate data (such as temperature and precipitation) and remotely sensed data (data measured by satellites) with computer simulation models of biological processes. The satellite data are used to estimate autotrophic biomass. The model combines this information with temperature and precipitation data, which largely determine the rate at which autotrophs photosynthesize and respire. The balance between these two is NPP. Using these methods, scientists estimate that terrestrial plants generate about 57 petagrams (62.8 billion tons) of carbon annually.

Humans use NPP in many ways. Food is the most obvious. All food is derived directly (like vegetables) or indirectly (like meat) from NPP. Humans also use NPP indirectly in the form of paper, fiber, and wood for energy or construction.

At first glance it seems easy to use their chemical composition to convert a kilogram of beef or paper to kilograms of carbon. But this simple approach would understate human use of net primary production. Much of what humans use is above-ground biomass. But this is often supported by a nearly equal amount of below-ground biomass. Similarly, economic production processes often discard a significant amount of the original material. For example, not all harvested timber is converted to wood that can be used for construction, and the remaining portions are sometimes wasted rather than being used for other purposes (such as paper).

The degree to which these indirect uses are included allows scientists to generate three estimates for the fraction of NPP used by society. At the low end, humans use about 3 percent of the NPP generated by terrestrial and aquatic ecosystems. This 3 percent represents only the organic material used directly by people or their domesticated animals.

A more inclusive estimate says that people use about 19 percent of the planet's NPP. This estimate includes both the NPP used directly by humans and the NPP lost as humans replace natural ecosystems with their own land uses. For example, as humans replace forests with croplands or pasturelands, the amount of NPP generated by these lands is reduced. This lost NPP is included in the 19 percent.

An even more inclusive estimate asserts that people use about 39 percent of the planet's NPP. This percentage includes the uses just described plus the secondary effects of human activity. Human activity erodes soils and emits wastes into the atmosphere. As described in

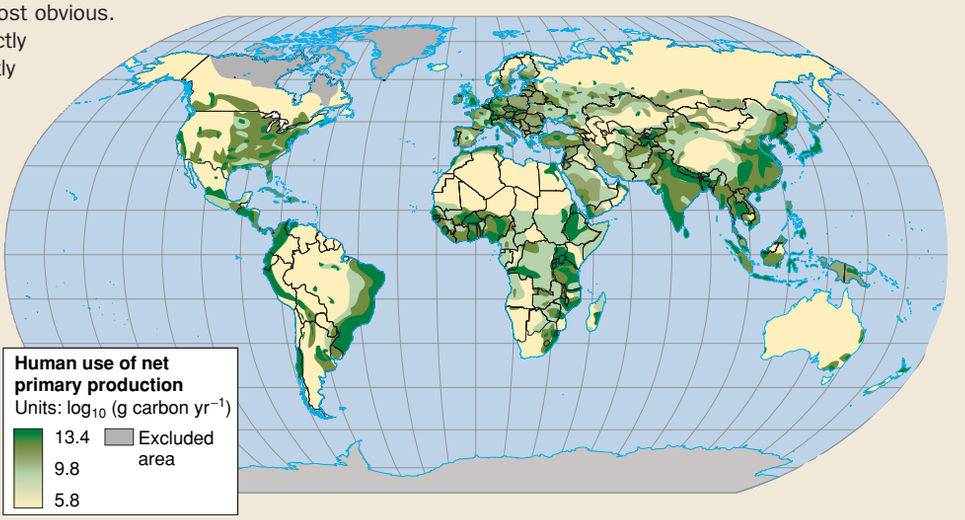

FIGURE 1 ***Human Use of Net Primary Production*** *Spatial representation of the human use of terrestrial net primary production. Notice that people living on the U.S. East Coast and in Europe, India, and China use the largest amounts of net primary production. (Figure from M. Imhoff* et al., *"Global Patterns in Human Consumption of Net Primary Production."* Nature *429 (2004): 870–873.)*

have reduced the area covered by forests, a process known as **deforestation.** By reducing the number of trees through burning and other uses, deforestation reduces the amount of carbon stored in the biota. Most of this carbon flows to the atmosphere. In the 1990s deforestation and other changes in land use caused 1–2 petagrams (1.1–2.2 billion tons) of carbon to flow from the biota to the atmosphere annually.

The other important set of flows moves carbon from the atmosphere to the ocean and from the ocean to the atmosphere. For a long time these two flows were approximately equal. This balance was created and maintained by

Chapters 15 and 19, respectively, these actions degrade environmental services. This degradation includes a reduction in NPP.

There is no "correct" answer regarding the fraction of NPP consumed by society. Including the indirect uses reduces the accuracy of the estimate. Nonetheless, it is clear that excluding these indirect uses significantly understates the effect of humans on the environment.

Scientists have calculated the quantity of NPP used by people in various locations (Figure 1). In general, people with a high material standard of living use more NPP than people with a lower material standard of living. The data used to generate this map are reproduced in Table 1. You can use this information to calculate your use of NPP. Sum your use of these products over a year, multiply by the conversion factor, and sum this number over all products. In Chapter 8 you will use this information to calculate the amount of land from which you draw these goods.

Calculating Your Footprint

We recognize that it may be difficult to fill in all of the blanks here. You should have compiled data about your diet in Chapter 5's Your Ecological Footprint (page 81). We will explore your use of paper and wood in Chapter 17's Your Ecological Footprint (page 318). You can either read ahead and use that information here, or use the average values for U.S. citizens, which are given in parentheses.

NPP consumed as plant-based food = (3,774) kcal/day × 0.36 gram/kcal × 365 days/year

NPP consumed as meat = (124) kg/year × 9,295 grams/kg

NPP consumed as milk = (115.8) kg/year × 501 gram/kg*

NPP consumed as eggs = (14.6) kg/year × 3,630 gram/kg**

NPP consumed as paper = (314) kg/year × 991 gram/kg

NPP consumed as wood = (1.06) m^3/year × 2,483 gram/m^3

** Milk weighs about 3.92 kg per gallon.*
*** An egg weighs about 56.7 grams (2 oz).*

Interpreting Your Footprint

Ecologists estimate that net primary production by Earth's terrestrial ecosystems is about 57 petagrams of carbon (quadrillion (10^{15} grams)). If all 6.48 billion (10^9) people used net primary production at the rate you just calculated, what fraction of global net primary production would people use?

This fraction is probably much larger than the 7 percent of terrestrial net primary production used directly by the human population that is estimated by ecologists. Why such a difference? As will be explained in Chapter 11, the average person living in the United States uses much more energy and material than the average denizen of the planet. To give you an idea of this difference, the average person living in 2002 used about 2,804 kcal of plant-based food per day, 39 kg of meat per year, 44 kg of milk per year, 8.4 kg of eggs per year, about 56 kg of paper per year, and about 0.51 m^3 of wood. Use these numbers to calculate the quantity of net primary production used by the average person. Do these calculations move you closer to the 7 percent estimate?

TABLE 1 The Grams of Carbon of NPP Used to Produce Various Products

Product	NPP Equivalent
Plant-based foods	0.36 grams carbon per kcal
Meat	9,295.2 grams carbon per kg
Milk	500.8 grams carbon per kg
Eggs	3,630.2 grams carbon per kg
Paper	990.8 grams carbon per kg
Wood (fuel)	2,483.4 grams carbon per m^3

Data from calculations by Imhoff et al., 2004.

ADDITIONAL READING

Imhoff, M.L., L. Buonoa, T. Ricketts, C. Loucks, Robert Harriss, and W.T. Lawrence. "Global Patterns in Human Consumption of Net Primary Production." *Nature* 429 (2004): 870–873.

Vitusek, P.M., P.R. Ehrlich, A.H. Ehrlich, and P.A. Matson. "Human Appropriation of the Products of Photosynthesis." *Bioscience* 36 (1986): 368–373.

the spontaneous flow of carbon from the storage of high concentration to the storage with the lower concentration. These movements created an equilibrium between the amounts of carbon in the atmosphere and ocean.

This equilibrium has been disrupted by the combustion of fossil fuels and deforestation. These two flows add carbon to the atmosphere, which increases the concentration of carbon in the atmosphere relative to the ocean. The greater atmospheric concentration of carbon causes carbon to flow spontaneously from the atmosphere to the ocean. The size of this flow is limited by a negative feedback loop, termed the Revelle factor. As carbon dioxide