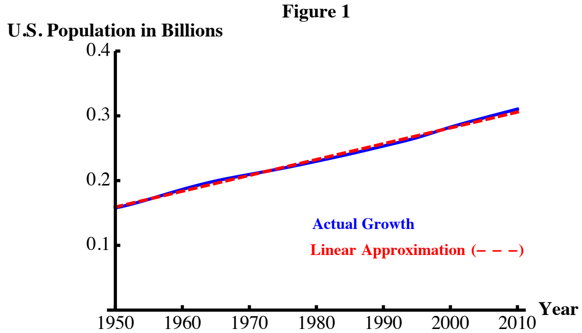
# Population Growth & Resource Capacity

## Part 1 Population Projections

Between 1950 and 2005, population growth in the U.S. has been nearly linear, as shown in figure 1.

Figure 1




Source: Population Division of the Department of Economic and Social Affairs of the United Nations Secretariat. *World Population Prospects: The 2010 Revision.*

If you looked at population growth over a longer period of time, you would see that it is not actually linear. However, over the relatively short period of time above, the growth looks nearly linear. A statistical technique called *linear regression* can create a linear function that approximates the actual population growth over this period very well. It turns out that this function is

$$P = 0.0024444t + 0.15914$$

where $t$ represents the time variable measured in years since 1950 and $P$ represents the (approximate) population of the U.S. measured in billions of people. (If you take statistics, you'll probably learn how to obtain this function.) The graph of this linear function is shown in the figure above.

(1) Just to make sure that you understand how to work with this function, use it to complete the following table. The actual population values are given. If you are working with the function correctly, the values you obtain should be close to the actual population values!

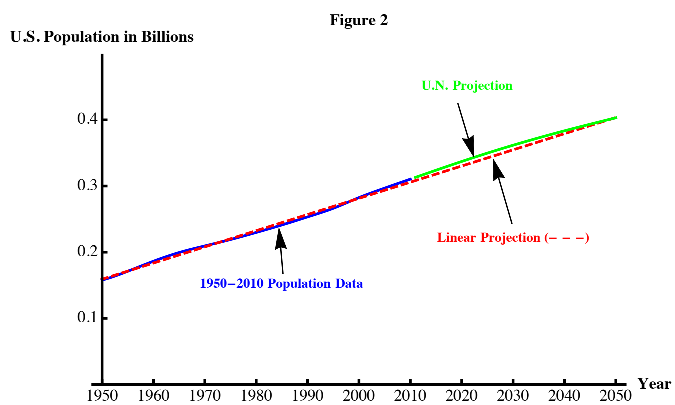
| Year | Actual Population (billions of people) | $t$ (years) | $P$ (billions of people) |
|---|---|---|---|
| 1960 | .186158 | | |
| 1990 | .256098 | | |
| 2005 | .299846 | | |

(2) Use the linear function to determine the approximate year when the population of the U.S. first reached 200 million people. Set up an equation and determine the answer algebraically.

Is your answer consistent with graph above?

(3) Explain what each of the values 0.0024444 and 0.15914 means in practical terms, using everyday language. In other words, what are these values telling you about the population of the U.S.?

Figure 2 shows the actual population growth during the 1950-2010 period, and two different population projections out to the year 2050. The first projection was generated by the United Nations. The second projection was obtained by extending the linear approximation above out past the year 2010.




From the graph, you can see that the linear projection is relatively close to the United Nations projection between 2010 and 2050. For the remainder of this project, we'll use the linear approximation to make population projections because the equation for this function is easier to work with.

(4) Use the linear approximation function $P = 0.0024444t + 0.15914$ to make population projections for the following years. Use the equation of the function, not the graph, to obtain your projections.

| Year | $t$ (years) | $P$ **(Projected Population)** (billions of people) |
|---|---|---|
| 2025 | | |
| 2050 | | |

You should check that your values are consistent with the graph.

(5) Use the linear approximation function to give the approximate year when the population of the U.S. first reaches 350 million people. Set up an equation and determine the answer algebraically.

## Part 2 Population Growth, Ecological Footprint and Biocapacity

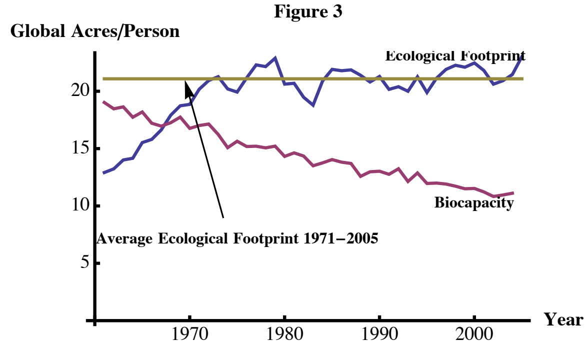
Biocapacity and Ecological Footprints represent the supply and demand sides, respectively, of our relationship with our natural environment. You can think of the Ecological Footprint as the area of biologically productive land required to support human demands for food, fiber, timber, energy and space for infrastructure, and also to absorb waste products. Biocapacity represents the area of biologically productive land (like forest land, cropland, and grazing land) available.

You have already estimated a few components of the current U.S. per capita Ecological Footprint. Estimating a person's total Ecological Footprint would require much more work. For example, you would need to consider the total land and water area required to produce all of a person's food, to absorb carbon dioxide emissions not only from driving a car, but also from heating a home and using electricity. Add to this the amount of land needed to produce all of the wood/paper/fiber products a person uses. Add to this the amount of land needed for a person's housing unit, and their share of all the developed land and infrastructure within the country. As the list goes on and on, the data requirements and the number of calculations grow. The Global Footprint Network (www.footprintnetwork.org ) has done extensive work in estimating both Ecological Footprints and Biocapacities for cities and countries all over the world. For the remainder of this project, we will explore potential implications of their calculations.

Note: The Global Footprint Network measures Ecological Footprints and Biocapacities in *global acres* rather than *acres*. A global acre is a unit of land area that also takes into consideration how biologically productive the area is. One global acre is equivalent to one acre of land with world average productivity. Since the world's productivity varies each year, so will a global acre. To keep matters simple, we will assume that a global acre remains the same over time, and just treat it as a unit of land area. (If you want to learn more about global acres, visit the Global Footprint Network's website www.footprintnetwork.org .)

Figure 3 shows the trends in U.S. per capita Ecological Footprints and Biocapacities between 1961 and 2005.

**Figure 3**




Source: Global Footprint Network (2008). Used with permission.

(6) The total Biocapacity of the US has remained fairly constant over time, at roughly 3.38 billion global acres. Despite this fact, the per capita Biocapacity is declining. Why is this?

(7) Notice also that the per capita Ecological Footprint has fluctuated since the early 1970s. The horizontal line shows the average per capita Ecological Footprint between the years 1971 and 2005—approximately 21.063 global acres. If the per capita Ecological Footprint continues to

linger abound 21 global acres, what will happen to the total Ecological Footprint of the U.S.? Will it increase, stay the same or decrease? Explain your answer.

(8) In what year do the two curves intersect each other? What is the U.S. population during this year?

(9) In the years preceding the intersection point, how do the per capita Ecological Footprint and Biocapacity compare? How do they compare in the years after the intersection point?

(10) In the years following the intersection point, the United States entered a state referred to as **overshoot**. In terms of sustainability, what does overshoot indicate? How do you think it is possible for a country experiencing overshoot to meet the needs/demands of its residents?

(11) In 2005, the per capita Ecological Footprint was approximately 23.0230 global acres while the per capita Biocapacity was approximately 10.80 global acres. How many times larger is the Ecological Footprint than the Biocapacity? (In other words, what number would you have to multiply the Biocapacity by in order to obtain the Ecological Footprint?) This number will tell you how many copies of the United States land area would be required to meet the current resource demands of people living in the United States.

(12) You saw from the graph above that the per capita Biocapacity of the U.S. is decreasing over time. Determine a function that models this decrease. In other words, determine a function equation in which $t$ represents an input time variable (in years since 1950) and $B$ represents the per capita Biocapacity output variable (in global acres per person). Recall that the total Biocapacity of the U.S. has been roughly constant at 3.38 billion global acres. (Hint: if you divide ‘billions of global acres’ by ‘billions of people’, the ‘billions’ cancel and you are left with global acres per person.)

(13) Use your per capita biocapacity function to complete the following table.

| Year | $t$ | $B$ (global acres per person per year) |
|---|---|---|
| 1950 | | |
| 2020 | | |
| 2050 | | |

(14) Suppose that the U.S. per capita Ecological Footprint continues to linger about 21.063 global acres for the foreseeable future, and that the per capita Biocapacity continues to decrease. Use your per capita Biocapacity function to determine the approximate year in which the per capita Ecological Footprint is three times the per capita Biocapacity. Write down the equation that you would have to solve and then solve this equation. Hint for solving equation: What can you do to eliminate fractions from an equation?

## Part 3 Ecological Footprint Reduction

Recall that the U.S. per capita Ecological Footprint in 2005 was approximately 23.0230 global acres. The table below shows how this estimate breaks down into its primary components.

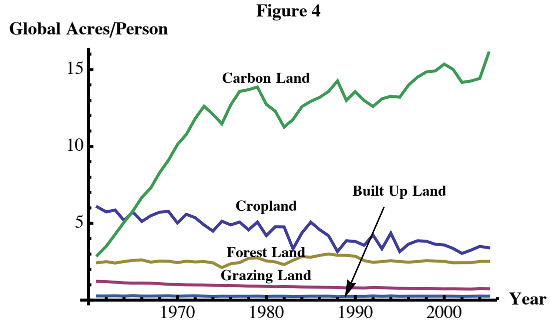
| **Ecological Footprint (global acres/person)** | |
|---|---|
| Cropland | 3.4102 |
| Grazing Land | 0.7435 |
| Forest Land | 2.5260 |
| Carbon Sequestration Land | 16.0844 |
| Built-up Land | 0.2589 |
| **Total** | **23.0230** |

Source: Global Footprint Network (2008). Used with permission.

(15) Recall that the per capita Biocapacity in 2005 was 10.80 global acres. The United States is experiencing overshoot. According to the table, which one component of the per capita Ecological Footprint is solely responsible for the overshoot?

Figure 4 shows the trends in these components over the period from 1961 to 2005.

Figure 4




(16) Discuss what you consider to be the noteworthy features of this graph.

In next few exercises, you will investigate hypothetical initiatives to reduce the Unites States carbon footprint over time (and therefore the overall Ecological Footprint) with the objective of ending overshoot by the year 2050.

(17) (**Initiative 1**) Suppose that the United States adopted energy policies in 2005 that would force the country's total carbon footprint to be cut by 10% every 20 years up to 2050. Will this initiative cause the carbon footprint to decrease linearly or exponentially over time?

Let $s$ represent the number of years since 2005 and let $C_1$ represent the total carbon footprint. Then, $C_1$ will be a function of $s$. Determine the equation for this function.

(18) (**Initiative 2**) Now suppose that the United States adopted energy policies in 2005 that would force the country's total carbon footprint to be cut by 500,000 global acres every 20 years up to 2050. Will this initiative cause the carbon footprint to decrease linearly or exponentially over time?

Let $s$ represent the number of years since 2005 and let $C_2$ represent the total carbon footprint. Then, $C_2$ will be a function of $s$. Determine the equation for this function.

(19) Now, lets see what affect these proposed carbon footprint reduction initiatives will have on the overall Ecological Footprint. Use the linear population growth function, the per capita Biocapacity function, and the two carbon footprint functions to make projections for the 2050 per capita Ecological Footprint. You can organize all of your calculations on the table provided. Space has been provided for you to write in your function equations.

| | | **2050** |
|---|---|---|
| | *t* (years since 1950) | |
| | *s* (years since 2005) | |
| | | |
| **Projections** | Population $P = 0.0024444t + 0.15914$ (billions of people) | |
| | | |
| | Per capita Biocapacity (global acres/person) | |
| | | |
| | **Initiative 1**—Total Carbon Footprint (billions of global acres) | |
| | Per capita Carbon Footprint (global acres/person) | |
| | Per capita Ecological Footprint (global acres/person) **Assuming no change in other components of the footprint since 2005 | |
| | | |
| | **Initiative 2**—Total Carbon Footprint (billions of global acres) | |
| | Per capita Carbon Footprint (global acres/person) | |
| | Per capita Ecological Footprint (global acres/person) **Assuming no change in other components of the footprint since 2005 | |
| | | |

(20) When you compare the per capita Ecological Footprint projection resulting from initiative 1 to the per capita Biocapacity projection in the year 2050 you should see that the Ecological Footprint is approximately 1.9 times the Biocapacity. (If you didn't arrive at this value, then you need to go back and check your work!) Has this initiative eliminated overshoot? Explain your answer using complete sentences.

(21) When you compare the per capita Ecological Footprint projection resulting from initiative 2 to the per capita Biocapacity projection in the year 2050 you should see that the Ecological Footprint is approximately 2.3 times the Biocapacity. (If you didn't arrive at this value, then you need to go back and check your work!) If you recall, the Ecological Footprint was approximately 2.1 times the Biocapacity in the year 2005 (see exercise 11). At first, this might seem impossible because initiative 2 reduced the size of the Ecological Footprint. By thinking more carefully about these calculations, determine why the factor in 2005 is smaller than the 2050 factor. Explain your answer using complete sentences.

(22) Propose one or more initiatives similar to the kinds of initiatives described in exercises 17 and 18 which, if implemented in 2005, would eliminate overshoot by the year 2050. There are many possibilities here. You should make an effort to create initiatives that you think might be plausible. (For example, eliminating overshoot by reducing the carbon footprint by 10% annually is probably not plausible.) In order to do this, you are welcome to consider reducing not only the carbon footprint but other components of the Ecological Footprint as well, namely the forest land footprint, crop land footprint, grazing land footprint, and built-up land footprint. If you wish, you can also propose initiatives that slow population growth in the U.S., but you may not consider policies that reverse population growth. (In other words, you can not require the United States population to decrease.)

Defend your proposed initiatives by creating mathematical functions that represent your proposed footprint reductions . Show that your functions eliminate overshoot by the year 2050. You will want to use a separate sheet of paper for this exercise.