ECOLOGICAL FOOTPRINT ANALYSIS AS A TOOL FOR ENVIRONMENTAL EDUCATION

Abstract

Ecological footprint (EF) analysis calculates the energy and resource needs of a population in terms of the land and water area required to sustain that population (Wackernagel and Rees 1996, Ferguson 2002, Wackernagel et al. 2002). This paper provides background information on ecological footprinting, especially as it relates to environmental education; curriculum ideas for teaching about environmental sustainability and resource use; and a classroom tool for calculating students' ecological footprints. Humanity's use of Earth's resources is not fixed in space or time; resource needs vary within and among countries, and as our global population grows there will be fewer available resources to support billions more people. Ecological footprint calculators such as the one presented here can be used as a hands-on method for exploring the connections among resource consumption, environmental sustainability, and global ecosystem processes.

Introduction

The past 100 years have been a time of unprecedented anthropogenic environmental changes in North America. These include dramatic expansion of urban and suburban areas and roadways, conversion of much of the continent's native prairie into cropland, impacts from extractive industries such as mining and timber harvesting, increasing use of ground and surface waters for agriculture and municipalities, and reduction in air quality resulting from fuel emissions. Urban populations have also grown increasingly dependent on importation of goods (food, clothing, building materials, automobiles, fuel, and sometimes water) from domestic and international sources, reducing the self-sufficiency of individuals, communities, and nations. As the Earth's population increases its inhabitants will place even greater demands on renewable and non-renewable resources. Estimations and projections suggest that the global population has increased from 2.5 billion people in 1950 to 6.1 billion in 2000, and may reach 8.9 billion by 2050 (United Nations 2004) (Figure 4.1). The global community is challenged now, and will continue to struggle, to balance human needs against those of other organisms.

Ecological footprint (EF) analysis is a quantitative method for assessing humanity's impact on the environment. Ecological footprint analysis incorporates biology, earth science, economics, and geography into a measurement tool that addresses the ways in which our levels of resource consumption affect Earth's abiotic and biotic resources, and influence global sustainability. The EF method is used to address such key questions as: What is the carrying capacity of the planet? Are we living within it? What is the relationship among population, the environment, and sustainability? How can we live well, while reducing our impact on the environment? Within the United States most children and adults have heard or read about some aspect of environmental sustainability, perhaps related to recycling, improved automotive fuel efficiency, or monitoring of water and air quality. Ecological footprinting brings many of the diverse elements of sustainability together - people, land, water, and air - and facilitates improved understanding of the Earth as a complex system. Residents of the United States have an especially compelling reason to evaluate their resource use, because the U.S. per capita footprint is the largest in the world (Wackernagel et al. 1997).

This paper describes ecological footprint analysis as a tool for ecology education in upper elementary and middle school grades. Although a number of science and policy research papers exist based on this and related concepts (Hall and Clover 1997, Wackernagel and Yount 2000, Ferguson 2002, Sanderson et al. 2002, Wackernagel et al. 2002, DeFries et al. 2004, Imhoff et al. 2004), very few papers explicitly address the role of EF analysis in education or provide an education framework for teachers (Venetoulis 2001, Camill 2002, Todd 2003, Schumaker-Chadde et al. 2004). As increasing emphasis is placed on issues of global concern including declining natural resources, population pressure, urbanization and land cover change, and increasing atmospheric CO_2 and associated climate trends, the understanding of human contributions to these processes is a timely lesson for tomorrow's environmental stewards.

The EF concept provides a powerful tool for helping students understand the relationships between resource consumption and ecological sustainability. Through EF analysis students can explore such topics as community planning, resource conservation, global change, landscape ecology, energy balance, food webs, and carrying capacity. Curricula built around EF analysis can be used to meet national science content standards for scientific inquiry and investigation, life science, science and technology, and science in social perspectives, enabling teachers to incorporate ecology topics into their teaching schedule while still meeting national guidelines and education requirements.

Ecological footprint calculators can help students understand human contributions to global change, and effects of those changes on global ecosystem processes. The EF tool provides a method for objectively evaluating resource-related issues, and integrates math, social studies, geography, and ecology into science teaching in an authentic and enriching manner. Helping students understand their resource use and its relationship to ecological sustainability at local, regional, and global scales may encourage innovation of alternative, more ecologically sustainable practices and ultimately reduce the flux of energy into and waste out of households, schoolyards, and communities.

The following sections of this paper include background on EF concepts, two take-home activities for students that provide a hands-on introduction to EF methods (Appendix A), and an ecological footprint calculator designed specifically for use with upper elementary and middle school students (Appendix B). I provide information on how and where ecological footprinting activities tie in with national science education standards, a list of resources related to ecological footprint analysis and sustainability that may supply additional teaching material, and a glossary of relevant terms. Whereas existing methods for calculating ecological footprints include web-based forms and complex spreadsheets, both of which may be difficult to use as teaching tools for younger audiences, the footprint calculator presented here is designed as an age-appropriate, paper-based instrument. By providing a classroom-ready ecological footprint calculator, along with background information and related teaching materials, I hope to address potential barriers to incorporating EF analysis into science education, and encourage teachers to explore the topic with their students.

What is ecological footprint analysis?

Ecological footprint analysis is used to calculate the energy and resource needs of individuals, populations, or regions in terms of the corresponding total land and water area required to meet those needs (Wackernagel and Rees 1996, Ferguson 2002, Wackernagel et al. 2002) (Figure 4.2). Ecological footprints represent the inverse of carrying capacity; whereas carrying capacity reflects the maximum number of individuals of a given species that a site can support, an ecological footprint calculates the size of the site required to support a human population of a given size (Camill, 2002). The average per-person ecological footprint in the United States is about 25 acres (Wackernagel et al. 1999), suggesting that in most communities human consumption exceeds the supply of local natural capital, resulting in the necessary importation of goods and exportation of waste products.

The ecological footprint of a given individual, community, region, or nation is not fixed in time, but can be reduced through implementation of more sustainable resource use and waste production practices. As with human demand, nature's supply of resources varies through time and is influenced by changes in land use (urbanization, deforestation), climate (drought), and natural disasters (flooding, forest fires). These changes underscore the need for adoption of more sustainable practices, because they reduce the **supply** of available biologically productive land, a loss that must be countered by a reduction in **demand** to avoid "ecological overshoot" (Wackernagel et al. 2002). A number of studies have estimated that although the total human population accounts for about 0.5% of the biomass of heterotrophic organisms on Earth, humans appropriate as much as 39% of the total food energy available on land (Vitousek et al. 1986, Rojstaczer et al. 2001, Imhoff et al. 2004). A recent analysis comparing humanity's demand to the supply of natural capital demonstrates that between 1961 and 1999 our use of Earth's resources increased from 70% to 120%, indicating that we have exceeded the global carrying capacity of our planet (Wackernagel et al. 2002) (Figure 4.3). Add to this scenario predictions for a global population of 8.9 million by A.D. 2050, and we are confronted with the possibility that our current appropriation of Earth's natural capital is likely to have catastrophic effects on global ecosystem processes in the decades to come. The good news is that ecological footprint analysis provides both the diagnosis and the cure for ecological overshoot, and can be used as a compass for directing our efforts toward global sustainability.

The EF concept was widely introduced in 1996 in the book *Our Ecological Footprint: Reducing Human Impact on the Earth* (Wackernagel and Rees 1996), in which the authors describe and quantify the impact of individuals on global ecological space in terms of the flux of resources into and waste out of communities. The authors envisioned EF analysis as a planning tool useful for exploring relationships between resource use and ecological sustainability. The original EF concept was also suggested as a method to “translate sustainability concerns into public action,” because built into its metrics are solutions for reducing ecological footprints at multiple scales, from individual to community to national. By design EF calculators allow users to evaluate the impact of their personal resource consumption on global sustainability, and iteratively modify a set of behaviors to reduce or increase their ecological footprint.

Ecological footprints are calculated by estimating the amount of land area needed to support an individual’s consumption of resources within five main categories: food, housing, transportation, consumer goods, and services (Wackernagel and Rees 1996). Simple mathematical equations are used to quantify resource consumption in terms of the total land area required to produce those goods and services consumed, including energy land (for fossil fuel production), consumed land (urban areas), used land (gardens, cropland, pasture, and managed forests), and limited availability land (non-managed forests and non-productive land such as ice caps or deserts). Because these land area types are not uniformly distributed across the landscape, ecological footprints typically encompass a far greater patch of land than the area immediately surrounding a particular city or region. Translated into simple terms, this means that most of us depend on goods and services that come from outside the boundaries of the communities in which we live (are imported), and the size of our ecological footprint proportionally reflects the degree to which we rely on these non-local goods and services. Ecological footprints differ significantly by country, from 1.25 acres per person in Bangladesh to 25.75 acres per person in the United States (Wackernagel et al. 1997) (Table 4.1).

Ecological footprint calculators use four basic equations to estimate individual and population footprints. They are:

(1) $\mathbf{c = \text{total consumption/population size}}$

where c is the average annual individual consumption of specific goods and services, measured in kilograms per capita and population size is the number of persons living within the community, region, or country of interest. Aggregate regional or national data on energy, food, and forest products production and consumption and census or other demographic data are used to parameterize this initial equation.

(2) $\mathbf{aa_i = c_i/p_i}$

where aa is an estimation of the land area appropriated per capita for the production of each major consumption item (i), and p is the average annual productivity or yield of that land area expressed in kilograms/hectare.

(3) $\mathbf{ef = \Sigma\, aa_i}$

$\mathbf{i = 1 \text{ to } n}$

where ef is the individual or per capita ecological footprint and $\Sigma\, aa_i$ is the summation of all ecosystem areas appropriated by that individual's annual consumption of goods and services.

(4) $\mathbf{EF_{population} = N(ef)}$

where N is the population size within the city, region, or country of interest.

In simple terms, an individual's consumption of goods and services is computed as a fraction of the population total consumption within a region of interest, translated into a spatial accounting of the amount of land area required to support that individual's consumption at an annual time step. This mass-to-area translation is calculated separately for various classes or categories of goods and services, and a final summation estimates the total land area or resource basin an individual requires for all of his/her resource needs (consumed food; fossil fuels used in transportation, food processing, and heating; waste disposal). To calculate the ecological footprint for a family, school, or community we multiply an individual's EF estimate by the size of the population of interest. This final computation assumes that all individuals within the population of interest share similar lifestyles in terms of resource consumption and waste production.

Ecological footprint calculators are available via the Internet and typically include questions related to food consumption, waste production, transportation, and housing (Redefining Progress 2002). Examples of such questions are:

What is the size of your home? How much of the food that you eat is locally grown, unprocessed and in-season? On average, how far do you go by car each week, as a driver or passenger? Activities that emphasize conservation of resources (i.e. use of public transportation and carpooling) and favor use of locally grown and processed goods result in a smaller calculated footprint, because less land area is required to offset resource consumption and waste production. By acquiring an understanding of the quantitative underpinnings of EF analysis teachers can escape the black box effect of canned web-based calculators, and provide students with a more content-rich approach to studying ecological sustainability.

Most available EF calculators are not straightforward enough to use in upper elementary and middle school classrooms because the metrics used to calculate the student's ecological footprint are expressed using wording that is too complex, or because EF calculations rely on information that is not readily available to the students. Many EF matrices are used as part of college curricula (Venetoulis 2001, Camill 2002), and require students to strictly monitor resource-related behaviors for periods of two weeks to a month. Some web-based EF calculators provide on-the-spot estimates but contain language that is not scaled to the comprehension level of most young students.

To address the problems with existing methods I developed an ecological footprint calculator specifically designed for younger students. This instrument uses a fairly standard set of questions for its calculations (Redefining Progress 2002) but has modified scoring metrics, structure, and language. I also developed two take-home activities that give students hands-on experience with evaluating their use of resources, and effects of these practices on global sustainability. I suggest that teachers direct students to complete these activities at home before introducing the ecological footprint calculator in the classroom, because the activities are designed to engage student interest and investment in EF concepts. Exploration of global sustainability, ecosystem processes, and resource consumption needs not be confined to the activities presented here. The following sections present curriculum ideas, a list of relevant resources, and suggestions for ways in which ecological footprint analysis can be used to meet national standards for science content, that may be useful for teachers who wish to integrate EF analysis with existing curricula.

Implementing ecological footprint analysis in the classroom

In an education context the ecological footprint concept is a useful tool for helping students to visualize the global natural resource base required to support individuals, families, and communities. Through EF analysis students can calculate their resource needs, compare these footprints with national and global average ecological footprints, and identify and implement practices and programs at the household, school and community levels to reduce dependence on non-sustainable goods and services. Ecological footprint analysis allows students to engage in an active, authentic learning process through which they are made aware of their contributions to the global ecological balance, and their ability to define and enact changes to improve our planet’s environment. Critical ecological issues related to EF analysis include global warming, habitat fragmentation, and air and water quality, because the human appropriation of natural resources results in reduced and/or poorer quality resources for other organisms and natural communities. Other related ecology topics include food webs, ecosystem interactions, carrying capacity, and energy balance; teachers can effectively draw analogy among our requirements for food, housing, transportation, goods and services as expressed in the ecological footprint concept, and similar requirements in natural systems.

To introduce ideas related to resource consumption and sustainability, ask students to list their basic needs. For humans as well as most terrestrial organisms, these are air, food, shelter, and water. What other needs do students have that consume resources? Are these resources finite or infinite, renewable or non-renewable? Although many students understand the fuel costs of automobiles, they may not be aware of associated mining and manufacturing costs. Conversely, students probably have an understanding of the land costs associated with growing grain crops used to produce cereal and bread products, but they may not account for water and fertilizer used in the growing process, or fuel costs of transporting crops from fields to manufacturing plants to markets. Concept maps can be used to help students understand the relationships between human needs and ecosystem goods and services. As mentioned above, food production requires the input of many hundreds of resources including soil, water, microorganisms, atmospheric gases, plant material, metals used to make machines to harvest and process food, petroleum products to drive those machines, and trees to absorb carbon emissions. Although not all system inputs can be easily identified, major requirements can be accounted for using an illustrated concept map. Using this method students develop a flowchart diagram for a particular food they eat, that shows the resource inputs required to produce and deliver that food item from farm to table. Rather than limit these diagrams to obvious primary inputs to the system (e.g. water, fuel, grass) students should consider secondary inputs such as those listed above.

One goal of ecological footprint analysis is to emphasize direct and indirect resource costs associated with our lifestyles, some of which we may not realize or may take for granted. Most of us rely to some degree on dry goods, food products, and energy resources that are imported, either from different regions of the United States or from other countries. In addition to the resource costs of growing, manufacturing, and extracting these products there are transportation costs associated with their importation. Similarly we are profoundly reliant on non-renewable energy resources (fossil fuels) to support our lifestyles, but may not be aware of some of the ecological implications of this dependence. The two take-home activities in Appendix A help students to evaluate the monetary, energy, and ecological costs inherent in typical American households, including use of inefficient incandescent bulbs and reliance on imported clothing and food items. After completing these activities students should have a better understanding of their personal contribution to global sustainability, be able to suggest some ways to reduce their resource consumption, and have the foundation knowledge required to understand and implement ecological footprint analysis.

The EF calculator in Appendix B provides students with an estimate of the amount of land area required to offset their use of food, housing, transportation, and consumer goods and services, and to account for waste production. The EF calculator returns the number of global acres needed, plus a calculation for the "number of Earths" necessary to support the student's lifestyle. The resource costs associated with the typical American lifestyle have reached global overshoot, but are offset by practices in less developed nations, where individuals typically use far fewer resources.

Teachers are encouraged to help students understand and implement mechanisms for reducing resource consumption. Students can use the EF calculator to make predictions about which lifestyle choices result in smaller or larger footprints, and iteratively test their predictions by modifying their quiz answers. Some lifestyle changes may be relatively easy to make, and some may be unreasonable - there are often inherent tradeoffs between meeting human needs for goods and services and achieving goals for ecological sustainability, including economic, social, and efficiency costs associated with reducing demand on natural capital (DeFries et al. 2004).

A place-based approach to teaching about resource use and its relationship to ecosystems will provide students with a meaningful context for understanding EF concepts. Place-based approaches focus on local environmental and resource management issues (e.g. noxious weed invasion, urban expansion, mining, logging, or water quality and availability). Because many of these issues are widely debated in popular media and local and state government forums, students may already possess useful background knowledge of and/or direct experience with relevant ecosystem components. The issues mentioned above influence regional sustainability in different ways: through reduction of available “useful land,” decreased landscape productivity, and through removal or contamination of renewable and non-renewable resources. As ecological degradation progresses through time and the amount of biologically productive land within a region decreases, ecological sustainability depends on implementation of resource-conserving strategies that reduce the ecological footprint of populations within that region. The ecological footprint calculator can be used to focus attention on the relationships between local ecological issues and resource conservation; in effect, to develop a conceptual understanding of ecology as a system in which flows of energy and waste exist at multiple scales and affect and are affected by actions at each of these scales.

Explaining resource sustainability and consumption in a familiar context gives students the tools and understanding necessary for implementing practices that favor sustainability and reduce ecological footprints at multiple scales. As part of the lesson students can be asked to brainstorm things they can do at home, school, or within the community to limit resource consumption, and implement those changes over a period of time. Several examples of student-driven conservation and sustainability programs exist in the literature, and provide good models for teachers interested in implementing similar programs

(Grant and Littlejohn 2001b, 2001a, Dunn Foundation 2002, Michigan State University Extension 2002, Chadde et al. 2004).

Additional information, lesson plans, and curricula related to ecological footprints and environmental sustainability are listed in the Resources section of this paper. There are a growing number of organizations devoted to promoting these ideas, including:

- **Redefining Progress** (http://www.redefiningprogress.org/)
- **Earth Day Network** (http://www.earthday.net/)
- **Creative Change Educational Solutions** (http://www.creativechange.net/
- **Facing the Future** (http://www.facingthefuture.org/)

These organizations provide curriculum ideas, detailed lesson plans, and teacher training materials useful for implementing environmental education in the classroom.

Ecological footprint analysis and the national science education standards

National science education standards are designed to help students attain scientific literacy, and call for student exposure to a “rich array” of learning materials and inquiry-based learning focused on critical thinking and application of the scientific method of observation, prediction, and hypothesis testing (National Research Council 1996). Teachers can use EF analysis to teach key ecology concepts and address current issues, while still meeting national standards for science education. A review of the national science education standards shows that ecological footprint analysis clearly fits within a number of the broad content categories and can be used to teach specific skills prescribed by the standards (Table 4.2). The content standards met through classroom implementation of the EF quiz and suggested extension ideas include science as inquiry, life science, science and technology, and science in social perspectives. Ecological footprint analysis can be used to fulfill prescribed learning goals and skills within each of the relevant content standards, for upper elementary and middle school students.

Conclusions

As tomorrow's environmental stewards, the current cohort of elementary and middle school students must obtain knowledge and skills necessary to make informed decisions, evaluate information, and think critically about issues of global concern. Ecological footprint analysis can be one useful tool for providing the foundation for an ecologically literate citizenry, who possess basic knowledge of the interconnectedness of human populations, natural resources, and natural communities that is fundamental to understanding today's environmental and ecological challenges. By participating in EF activities students can develop an awareness of their importance within the global ecology as producers and consumers, and as citizens who can make lifestyle changes to promote resource conservation and sustainability.

Population and resource use trends suggest that our demands on Earth's natural capital will increase, requiring new technological solutions, practices, and attitudes to avoid catastrophic ecological overshoot. Exploration of the ecological footprint concept gives students the ability to participate in decision-making and cost-benefit analysis, and design strategies or programs by which they can make changes at the individual, school, or community scale. Ecological footprint analysis can be used to introduce and reinforce key concepts in ecology including energy balance, food webs, and carrying capacity; many of the same cost-benefit tradeoffs that influence our decisions are also present within natural systems, and non-human species are also subject to population pressures and resource limitations.

By addressing some of the obvious barriers to introducing ecological footprint analysis in primary and middle school classrooms I hope to encourage teachers to explore this and related concepts with their students. In particular, a place-based approach which emphasizes local environmental or ecological issues may provide a compelling context for learning, and offer an arena in which students can make lifestyle changes to promote sustainable communities. The ecological footprint quiz presented here may also encourage teachers to include ecological footprint analysis as part of their science curriculum, because it is scaled to favor younger users, is easily administered, and can be integrated into the curriculum as part of the nationally-prescribed science content.

The list of resources for teachers contained in this paper is inclusive but by no means exhaustive. Many additional curriculum units, activities, lessons, and papers related to resource sustainability and community planning exist that may provide valuable material for teachers and students, although, as mentioned, few explicitly address the use of ecological footprint calculators in the classroom. Since the introduction of the ecological footprint concept in 1996, it has grown in application to include research in ecology, economics, public policy, and planning, community land-use and sustainability projects, environmental analysis and conservation studies, and education. Continued use of ecological footprint analysis to teach about resource sustainability and conservation promotes a community of ecologically-aware students, who will already be conversant with EF concepts when they encounter them as older students or adults. The development of lessons or curricula focused on use of ecological footprint calculators in the classroom is a critical step in establishing the effectiveness of ecological footprint analysis as a tool for environmental education.

Resources for Teachers

Web-based Ecological Footprint Calculators

- Redefining Progress *http://www.redefiningprogress.org/*
- Adventures with Bobbie Bigfoot *http://www.kidsfootprint.org/index.html*

Data sources for Ecological Footprint calculations

- Food and Agriculture Organization (FAO) of the United Nations *http://faostat.fao.org/*
- United Nations Development Program (UNDP) *http://hdr.undp.org/statistics/data/*
- World Resources Institute EarthTrends Environmental Information Portal *http://earthtrends.wri.org/*
- Worldwatch Institute *http://www.worldwatch.org/*

Supplemental information for the Ecological Footprint Quiz

- Information on green building techniques *http://www.greenhomebuilding.com/*
- EPA's Fuel Economy Guides, 2000-2006 *http://www.fueleconomy.gov/feg/FEG2000.htm*
- *Five Things Your Community Can Do To Reduce Its Ecological Footprint* *http://www.regionalprogress.org/StepstoSustainability.pdf*
- Ecological Footprints of Nations Report, 2004 *http://www.rprogress.org/newpubs/2004/footprintnations2004.pdf*
- Ecological Footprint FAQs *http://www.rprogress.org/newprojects/ecolFoot/faq/index.html#accuracy3*

Curriculum Links

- *Looks Count! Community Planning, Natural Resource Protection and the Visual Environment: An Interdisciplinary Middle School Curriculum Unit for Social Studies, Language Arts, Math, Science, and Art.* http://wupcenter.mtu.edu/education/land_use/
- *This Land is Your Land* by Michigan State University Extension: Land use curriculum materials designed to help students understand the importance and practice of wise land use. *http://www.msue.msu.edu/*
- Redefining Progress K-12 Lesson Plans *http://www.redefiningprogress.org/newprograms/sustIndi/education/k-12lessonplans.shtml*
- Creative Change Educational Solutions *http://www.creativechange.net/*
- Facing the Future *http://www.facingthefuture.org/*
- Earth Day Network *http://www.earthday.net/*

Glossary of terms

Abiotic – nonliving components of the environment, including light, climate, atmosphere, rocks, and minerals.

Acre - 4,840 square yards. One hectare contains 2.47 acres, or 10,000 square meters. An acre is approximately the size of an American football field, not counting its end zones.

Anthropogenic – caused by humans.

Autotrophic – an organism capable of synthesizing its own food from inorganic substances, using light or chemical energy. Green plants, algae, and certain bacteria are autotrophs.

Available biological capacity - the amount of biologically productive space that is available for human use.

Biotic – of or having to do with life or living organisms.

Carrying capacity – the maximum number of individuals that a given area can support without detrimental effects.

Ecological footprint - a measure of the amount of productive land and water an individual, city, country, or the world requires to produce all the resources it consumes and to absorb all the waste it generates, using prevailing technology.

Ecological overshoot - when human demand exceeds nature's supply at the local, national, or global scale.

Ecology – the study of the relationships between organisms and their environment.

Energy balance - the state in which the total energy intake equals total energy need.

Flux – flow.

Food chain - A succession of organisms in an ecological community that constitutes a continuation of food energy from one organism to another as each consumes a lower member and in turn is preyed upon by a higher member.

Food web - An organism that cannot synthesize its own food and is dependent on complex organic substances for nutrition.

Global warming - an increase in the near surface temperature of the Earth. Global warming has occurred in the distant past as the result of natural influences, but the term is today most often used to refer to the warming some scientists predict is occurring as a result of increased anthropogenic emissions of greenhouse gases.

Greenhouse effect - the effect of the Earth's atmosphere, due to certain gases, in trapping heat from the sun; the atmosphere acts like a greenhouse.

Greenhouse gases - gases that trap the heat of the sun in the Earth's atmosphere, producing the greenhouse effect. The two major greenhouse gases are water vapor and carbon dioxide. Lesser greenhouse gases include methane, ozone, chlorofluorocarbons, and nitrogen oxides.

Heterotrophic - an organism that cannot synthesize its own food and is dependent on complex organic substances for nutrition.

Natural capital - the stock of natural assets that yield goods and services on a continuous basis. Main functions include resource production (such as fish, timber or cereals), waste assimilation (such as CO_2 absorption or sewage decomposition) and life support services (biodiversity, water cleansing, climate stability).

Non-renewable resources – materials that exist in finite amounts and cannot be replenished, such as fossil fuels or metals.

Productivity - a measurement of biological production per acre per year. A typical indicator of biological productivity is the annual biomass accumulation of an ecosystem.

Renewable resources – materials that can be replaced through natural processes; examples are solar energy or trees.

Sink – an area in which more resources are used than are produced.

Source – an area in which more resources are produced than are used.

Sustainability – living within the carrying capacity of the Earth’s life support systems.

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Table 4.1 Ecological footprints of nations in acres per capita (Data source: Wackernagel et al. 1997)

Country	Ecological Footprint	Available Capacity	Ecological Overshoot
Argentina	9.75	11.50	1.75
Australia	22.50	35.00	12.50
Austria	10.25	7.75	-2.50
Bangladesh	1.25	0.75	-0.50
Belgium	12.50	3.25	-9.25
Brazil	7.75	16.75	9.00
Canada	19.25	24.00	4.75
Chile	6.25	8.00	1.75
China	3.00	2.00	-1.00
Colombia	5.00	10.25	5.25
Costa Rica	6.25	6.25	0.00
Czech Rep	11.25	10.00	-1.25
Denmark	14.75	13.00	-1.75
Egypt	3.00	0.50	-2.50
Ethiopia	2.00	1.25	-0.75
Finland	15.00	21.50	6.50
France	10.25	10.50	0.25
Germany	13.25	4.75	-8.50
Greece	10.25	3.75	-6.50
Hong Kong	15.25	0.00	-15.25
Hungary	7.75	5.25	-2.50
Iceland	18.50	54.25	35.75
India	2.00	1.25	-0.75
Indonesia	3.50	6.50	3.00
Ireland	14.75	16.25	1.50
Israel	8.50	0.75	-7.75
Italy	10.50	3.25	-7.25
Japan	10.75	2.25	-8.50
Jordan	4.75	0.25	-4.50
Korea, Rep	8.50	1.25	-7.25
Malaysia	8.25	9.25	1.00
Mexico	6.50	3.50	-3.00
Netherlands	13.25	4.25	-9.00
New Zealand	19.00	51.00	32.00
Nigeria	3.75	1.50	-2.25
Norway	15.50	15.75	0.25
Pakistan	2.00	1.25	-0.75
Peru	4.00	19.25	15.25
Philippines	3.75	2.25	-1.50
Poland, Rep	10.25	5.00	-5.25
Portugal	9.50	7.25	-2.25
Russian Federation	15.00	9.25	-5.75
Singapore	18.00	0.25	-17.75
South Africa	8.00	3.25	-4.75
Spain	9.50	5.50	-4.00
Sweden	14.75	17.50	2.75
Switzerland	12.50	4.50	-8.00
Thailand	7.00	3.00	-4.00
Turkey	5.25	3.25	-2.00
United Kingdom	13.00	4.25	-8.75
United States	25.75	16.75	-9.00
Venezuela	9.50	6.75	-2.75
WORLD	7.00	5.25	-1.75

Table 4.2 Tie-ins between ecological footprint analysis and the National Science Education Content Standards (National Research Council 1996).

National Science Education Standard	Skills Base	Grade Level
A: SCIENCE AS INQUIRY		
Abilities necessary for scientific inquiry	Ask a question about objects, organisms, or events	K-4
	Communicate investigations and explanations	K-4
	Identify questions and concepts that guide scientific investigations	5-8
	Use technology to gather, analyze, and interpret data	5-8
	Develop descriptions, explanations, and models	5-8
	Use mathematics in all aspects of scientific inquiry	5-8
C: LIFE SCIENCE		
Characteristics of organisms	Basic needs of organisms	K-4
	Behavior of organisms and their environmental contexts	K-4
Organisms and their environments	Interdependence of organisms	K-4
	Response of organisms to environmental change	K-4
	Human dimensions of environmental change	K-4
Regulation and behavior	An organism's behavior evolves through adaptation to its environment	5-8
Populations and ecosystems	Matter, energy and organization in living systems	5-8
E: SCIENCE AND TECHNOLOGY		
Understanding about science and technology	Invention of tools and techniques to solve scientific problems	K-4
	Technological solutions have side effects, and carry costs, risks and provide benefits, and have constraints	5-8
	Perfectly designed solutions do not exist; all solutions have tradeoffs and unintended consequences	5-8
F: SCIENCE IN PERSONAL AND SOCIAL PERSPECTIVES		
Characteristics and changes in populations	Changes in population density over time and across the landscape	K-4
Types of resources	Basic characteristics of resources	K-4
	Resource limitations and conservation	K-4
Science and technology in local challenges	Effects of inventions, ideas, and ways of solving problems	K-4
Populations, resources, and environments	Causes of environmental degradation and effects of overpopulation on the environment	5-8
Natural hazards	Human activities can induce resource-related hazards	5-8
Risks and benefits	Individuals can use systemic approaches to thinking critically about risks and benefits	5-8

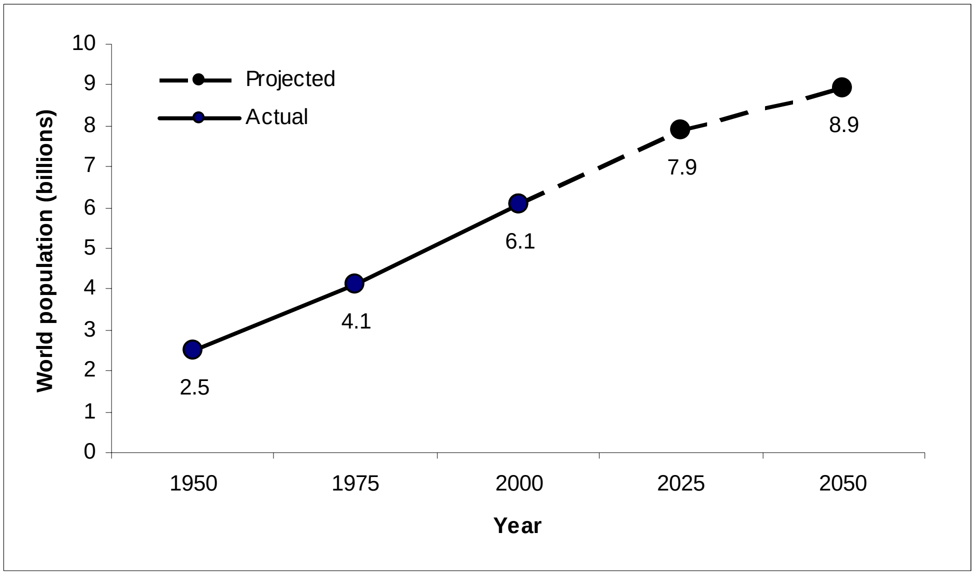

Figure 4.1 Actual (1950-2000) and projected (2000-2050) world population in billions of people (Data source: United Nations 2004).

Figure 4.2 Ecological footprint (From Zero Waste Services, http://www.zerowaste.ca/)

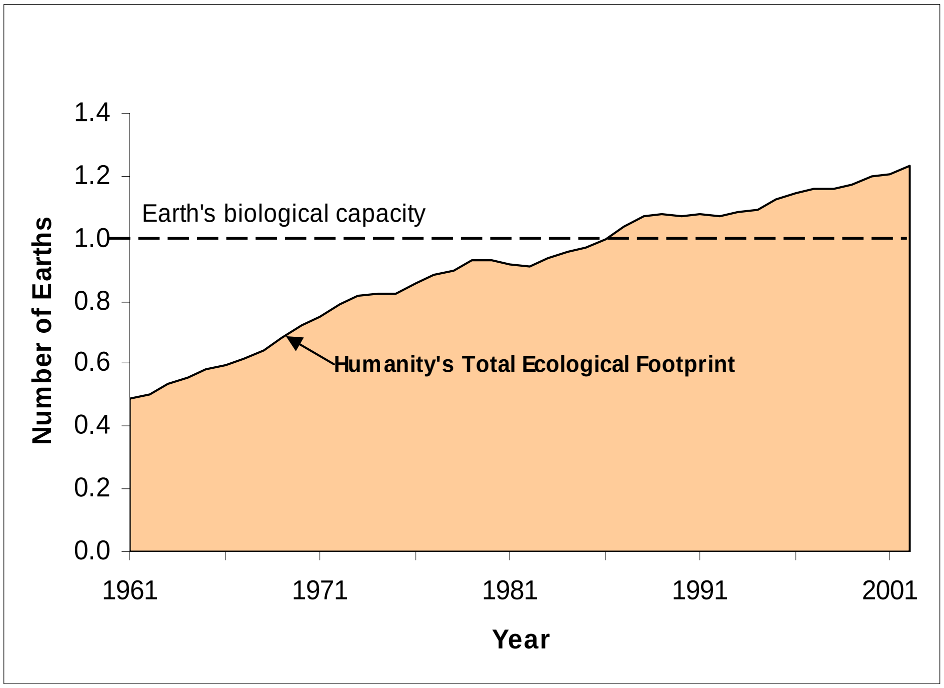

Figure 4.3 Ecological overshoot, 1961-2002. The dashed line represents the Earth's biological capacity, and the shaded region is resource use relative to that capacity, demonstrating that by 2002 global overshoot equaled about 120% of Earth's available resources. (Data source: Global Footprint Network 2005).

APPENDIX A

Change a Bulb – Save a Watt!

Did You Know?

Incandescent bulbs, the type used by most people in the light fixtures in their houses, waste considerable energy compared to **compact fluorescent** (CF) bulbs. Incandescent bulbs use about 90% of their energy making a metal element inside the bulb white-hot – this is what produces light. By comparison, CF bulbs create light by passing electricity through a gas trapped in the bulb, so much less heat energy is lost and CF bulbs are more energy efficient. The energy wasted by incandescent bulbs costs money (see the table below), creates pollution (because the electricity needed to power the bulbs often comes from pollutant sources such as coal-fired power plants, which release **greenhouse gases** into the atmosphere), and may cause harmful climate changes. Some greenhouse gases that affect global climate are carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O)[1].

The burning of **fossil fuels** for energy is thought to have increased Earth's average temperature by about 0.6 °Celsius (33 °Fahrenheit) over the past 100 years[2], and **global warming** will likely continue in the future unless we reduce the amount of greenhouse gases we put into the atmosphere   Effects of increased temperatures include melting of polar ice caps and glaciers, droughts, loss of valuable coastal areas, spread of diseases, death of ocean corals, and loss of important habitat areas for plants and animals[3].

You can make a difference! Using electricity isn't wrong, but we can figure out how to use energy in smarter and more efficient ways. The average American home uses about 30 incandescent light bulbs, 3 of which burn for 5 or more hours per day. If we all replaced just 3 of these bulbs with CF bulbs, we could save as much electricity as is produced by 11 fossil-fuel fired power plants, prevent about 23 million tons of CO_2 from entering the atmosphere, and save about $1,800,000,000[4]! Complete the activities below to figure out how much electricity you use to light your house, and how much you can save by switching to energy efficient light bulbs.

What other things can you do to help make the planet a better place?

Incandescent vs. Compact Fluorescent Light Bulbs

Bulb Type	100 Watt Incandescent	23 Watt Compact Fluorescent
Purchase price	$0.75	$11.00
Life of the bulb	750 hours	10,000 hours
Number of hours burned per day	4 hours	4 hours
Number of bulbs needed	6 per 3 year period	1 per 7 year period
Total cost of bulbs	$4.50	$11.00
Lumens produced	1,690	1,500
Total cost of electricity	$35.04	$8.06
Total cost over 3 years	$39.54	$19.06

Source: Energy Information Administration, U.S. Department of Energy

[1] Energy Information Administration, U.S. Department of Energy, http://www.eia.doe.gov/
[2] Intergovernmental Panel on Climate change, http://www.ipcc.ch/
[3] Environmental Protection Agency, http://www.epa.gov/globalwarming/kids/
[4] Ban the Bulb, http://banthebulb.org

Collect Data

1. Record the number of light bulbs in each room of your house. Halogen bulbs use more energy than incandescent bulbs, and must be counted three times. If you already use compact fluorescent bulbs in some of your light fixtures, do not count these.

2. Calculate the total number of non-CF bulbs in your house by adding all the numbers in the first column of your data sheet. Calculate the total number of hours each day you use these bulbs by adding the numbers in the second column of your data sheet. Multiply these two totals together to calculate the total hours of operation for all the non-CF bulbs in your house. You will use this information later in the exercise.

	Number of bulbs in each room	**Number of hours used each day**
Living Room		
Dining Room		
Family Room		
Kitchen		
Bedrooms		
Bathrooms		
Hallways		
Basement		
Garage		
Outside		
Other		

Total number of non-CF bulbs in your house = ________

Total number of hours used each day = ________

Total hours of operation (number of bulbs x number of hours used each day) = ________

"Watts" Your Use?

What would happen if you replaced all the incandescent or halogen light bulbs in your house with compact fluorescent (CF) bulbs? Use the questions below to figure out how much energy you would save in a year.

1. Each energy-efficient compact fluorescent bulb saves 55 watts. How many watt-hours could you save each day by changing to CF bulbs?

________ **WATT-HOURS SAVED EACH DAY** **=** ________ **TOTAL HOURS USED EACH DAY** **X** **55 WATTS**

2. Your utility company measures your electricity use in kilowatt-hours (look at your utility bill). How many kilowatt-hours each day would you save by switching to CF bulbs?

_______	**KILOWATT-HOURS SAVED EACH DAY**	**=**	_______	**WATT-HOURS SAVED EACH DAY**	**÷**	**1000**

3. How many kilowatt hours would you save in a year by switching to CF bulbs?

_______	**KILOWATT-HOURS SAVED EACH YEAR**	**=**	_______	**KILOWATT-HOURS SAVED EACH DAY**	**X**	**365**

4. By using less electricity we produce less carbon dioxide (CO_2), a greenhouse gas, and every kilowatt hour you save keeps about 2 pounds of CO_2 from entering the atmosphere. How much CO_2 will you keep out of the atmosphere in a year by changing to CF bulbs?

_______	**POUNDS OF CO_2 SAVED EACH YEAR**	**=**	_______	**KILOWATT-HOURS SAVED EACH YEAR**	**X**	**2**

5. How much money will your family save in a year by switching to CF bulbs? Look on your utility bill to find the amount you pay per kilowatt-hour. The information on your bill should look something like this:

Energy Charge 3489 KWH @ 0.09526 332.3

meaning that you pay 9.5¢ per kilowatt-hour. If you don't know how much your utility company charges, use the rate for Denver, 8.9¢ per kilowatt-hour.

_______	**AMOUNT OF MONEY SAVED EACH YEAR**	**=**	_______	**KILOWATT-HOURS SAVED EACH YEAR**	**X**	**COST PER KILOWATT-HOUR**

Map Your Use!

Did You Know?

Most of us rely on and use dry goods (clothing, cars, books, etc.) and food products that are **imported** (brought in from outside our region, state, or country). In addition to the resources and raw materials used to grow, process, and manufacture these products money and energy are required to import them to your local stores. Burning **fossil fuels** for energy to power the trains, airplanes, ships, and trucks that transport goods around the world releases carbon dioxide (CO_2), a **greenhouse gas**, into the atmosphere. The buildup of atmospheric CO_2 over the past 100 years has increased global average temperatures by about 0.6 °Celsius (33 °Fahrenheit)[5], causing melting of polar ice caps and glaciers, droughts, loss of valuable coastal areas, spread of diseases, death of ocean corals, and loss of important habitat areas for plants and animals[6].

<u>You can make a difference!</u> Buying imported food and clothing isn't wrong, but we can figure out how to use energy in smarter and more efficient ways. The average American car releases about 1 pound of CO_2 for every mile driven,[7] and larger, less-efficient vehicles (trucks, airplanes, ships) release even more CO_2. Can you think of some things you can do to reduce resource costs associated with your clothing and food needs? Complete the activities below to figure out where your food and clothing comes from, and how much CO_2 was released in transporting it to your local store.

Instructions

3. Mark the approximate location of the place where you live on the attached Clothing and Food maps.

4. Choose three pieces of clothing from your closet or dresser, and use the sewn-in tags to find out where those items were manufactured. Use the data sheet to record a description of each item (ex. "T-shirt," "jeans"), and locate and mark its place of manufacture on the Clothing map. If the tag lists more than one location (ex. "Fabric made in U.S.A., assembled in El Salvador) mark and label both locations on the map.

5. Choose three packaged food items from your pantry or refrigerator, and use the packaging to find out where those products were manufactured. Record a description of each item (ex. "cheese," "Cheerios") in the data sheet. Locate and mark its place of manufacture on the Food map.

6. Using a ruler and the scale bar underneath each map, calculate the distance from each of the marked points to the place where you live, and record that distance in the data sheet in the Distance column.

Suggested materials

- World map or atlas
- Pencil
- Ruler

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[5] Intergovernmental Panel on Climate change, http://www.ipcc.ch/
[6] Environmental Protection Agency, http://www.epa.gov/globalwarming/kids/
[7] Energy Information Administration, U.S. Department of Energy, http://www.eia.doe.gov/

Collect Data

My Closet	Item description	Distance

My Kitchen	Item description	Distance

Total clothing import distance = ________ miles

Total food import distance = ________ miles

Clothing + food import distance = ________ miles

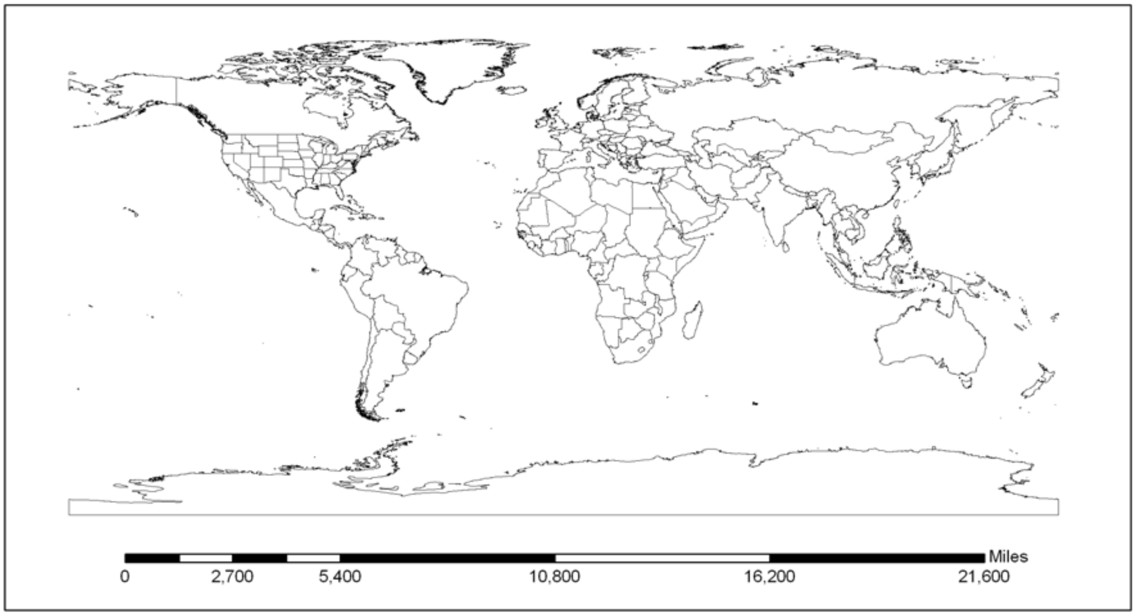
Compute Your Use

Assume that for each mile your clothing and food travel from where they were made to your local store 1 pound of CO_2 is released (this is a conservative estimate because larger vehicles release more CO_2). How many pounds of CO_2 were released in importing the clothing and food listed in your data sheet?

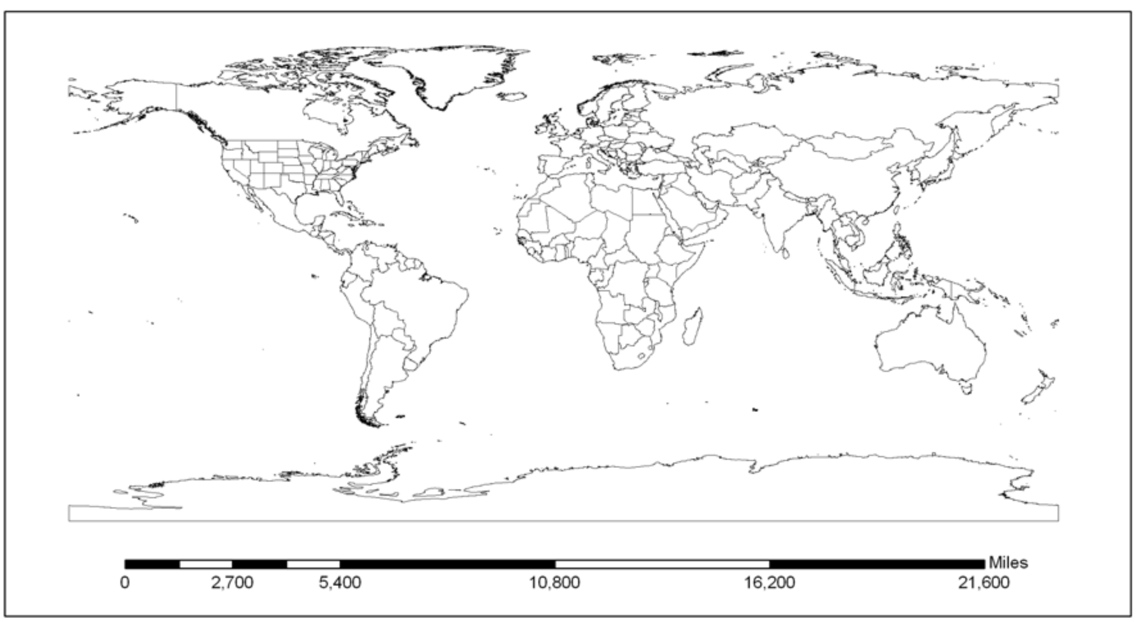
________ POUNDS OF CO_2 RELEASED = ________ TOTAL IMPORT MILES X 1 POUND CO_2

What other things can you do to help make the planet a better place?

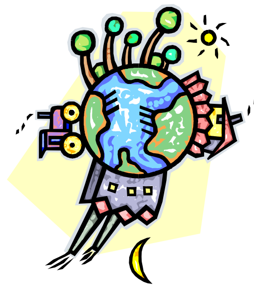
Clothing Map



Food Map



APPENDIX B



YOUR ECOLOGICAL FOOTPRINT

A QUIZ TO HELP YOU UNDERSTAND YOUR IMPACT ON THE EARTH

Have you ever wondered about the amount of resources it takes to support your lifestyle? Your lifestyle is everything about you: the food you eat, the places you shop, the house you live in, the cars you or your parents drive, and the things you throw away. This quiz estimates how much productive land and water is needed to grow your food, produce building materials, heat, and water for your house, manufacture and power your cars, and account for the trash and waste you produce. After taking this quiz you'll be able to compare the resources you use to the total available amount on this planet (in global acres), and figure out ways that you can reduce your impact on the Earth.

INSTRUCTIONS

1. For each numbered question find the answer that best describes you
2. Fill in the answer in the labeled boxes on your score sheet
3. Use the score sheet to calculate your footprint for each section (Food, Goods, Shelter, Mobility)
4. To find your total ecological footprint transfer the scores for each section into the boxes in the TOTAL ECOLOGICAL FOOTPRINT grid and calculate your total footprint using the equations provided

****Note: For some sections you will have to multiply or divide your scores by other numbers**

SUGGESTED MATERIALS

1. Pencil
2. Calculator

FOOD FOOTPRINT

1. How often do you eat animal-based foods (beef, pork, chicken, fish, eggs, milk products)?

a) **Never** (vegan)	0.46
b) **Not very often** (no meat; eggs/dairy a few times a week)	0.59
c) **Sometimes** (no meat or infrequent meat; eggs/dairy almost daily)	0.73
d) **Often** (meat once or twice a week, eggs/dairy almost daily)	0.86
e) **Very often** (meat daily, eggs/dairy daily)	1.00
f) **Almost always** (meat and eggs/dairy in almost every meal)	1.14

2. How much of your food did you, your family, or someone living near you grow or produce? Examples of locally produced foods are vegetables from your garden or a farmer's market, or locally-hunted game. If your food comes from a supermarket, chances are it's not locally grown or produced.

a) **Most or all**	0.69
b) **More than half**	0.79
c) **Half**	0.90
d) **Less than half**	1.00
e) **Almost none** (most of my food is processed or packaged)	1.10

GOODS FACTOR

3. Compared with people in your neighborhood, how much trash do you throw away?

a) Much less trash	0.75
b) About the same amount of trash	1.00
c) Much more trash	1.25

SHELTER FOOTPRINT

4. Which describes your home?

a) **Green-design home** (powered by sun or wind; made of recycled materials; energy efficient design and appliances)	0.50
b) **Multistory apartment building**	0.80
c) **Free-standing house**	1.00

5. What is the size of your home? (The average U.S. house size is 1,700 square feet.)

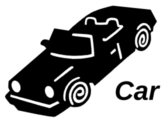
a) **500 square feet or smaller** (studio apartment; no bedrooms, 1 bath)	0.30
b) **500-1,000 square feet** (1 bedroom, 1 bath)	0.60
c) **1,000-1,500 square feet** (2 bedrooms, 1 bath)	0.90
d) **1,500-1,900 square feet** (2 bedrooms, 2 baths)	1.30
e) **1,900-2,500 square feet** (3 bedrooms, 2 baths)	1.50
f) **2,500 square feet or larger** (4 bedrooms, 2 baths or larger)	1.90

6. Does your house have energy efficient features (solar panels, compact fluorescent light bulbs, or EnergyStar appliances)?

a) **All energy efficient features**	0.70
b) **Some energy efficient features**	0.85
c) **No energy efficient features**	1.00

7. How many people live in your house, including you?

a) **Seven or more**	7.00
b) **Six**	6.00
c) **Five**	5.00
d) **Four**	4.00
e) **Three**	3.00
f) **Two**	2.00
g) **One**	1.00



MOBILITY FOOTPRINT

Car Travel Subtotal

8. On average, how many miles do you travel each week in a car (as a driver or a passenger)?

a) **0 miles**	0.00
b) **1 - 100 miles**	0.12
c) **101 - 200 miles**	0.55
d) **201 - 300 miles**	1.00
e) **301 - 400 miles**	1.43
f) **More than 400 miles**	1.91

9. How fuel efficient is your car? (or estimate the average fuel efficiency of the cars you ride in.)

a) **I don't travel by car**	0.00
b) **Very fuel efficient** (More than 50 mpg: hybrid gas-electric cars)	0.31
c) **Fuel efficient** (35-50 mpg: compact and sub-compact cars)	0.46
d) **Somewhat fuel efficient** (25-34 mpg: midsize cars and wagons)	0.65
e) **Not very fuel efficient** (15-24 mpg: smaller sport utility vehicles and trucks)	0.98
f) **Not fuel efficient at all** (fewer than 15 mpg: full-sized trucks, vans, and SUVs)	1.54

10. How often do you ride in a car with someone else (carpool)?

a) **I don't travel by car**	0.00
b) **Almost always**	0.50
c) **Very often** (about 75% of the time)	0.60
d) **Often** (about 50% of the time)	0.75
e) **Sometimes** (about 25% of the time)	1.00
f) **Almost never**	1.50

MOBILITY FOOTPRINT CONTINUED

Public Transit Subtotal

11. On average, how many miles do you travel on public transportation each week (bus, train, subway, or ferry)?

a) **0 miles**	0.00
b) **1 - 25 miles**	0.04
c) **26 - 75 miles**	0.15
d) **76 - 200 miles**	0.42
e) **More than 200 miles**	0.86

Air Travel Subtotal

12. About how many hours do you spend in an airplane each year?

a) **0 hours**	0.00
b) **3 hours**	0.18
c) **10 hours** (one coast-to-coast US round-trip per year)	0.60
d) **25 hours** (two or three coast-to-coast U.S. round-trips per year)	1.50
e) **100 hours** (one coast-to-coast US round-trip per month)	6.00

ECOLOGICAL FOOTPRINT SCORE SHEET

FOOD FOOTPRINT	
Your score for Question 1 (Q1)	
Your score for Question 2 (Q2)	
YOUR FOOD FOOTPRINT = Q1 x Q2 x 5.5	

GOODS FACTOR	
Your score for Question 3 (Q3)	

SHELTER FOOTPRINT	
Your score for Question 4 (Q4)	
Your score for Question 5 (Q5)	
Your score for Question 6 (Q6)	
Your score for Question 7 (Q7)	
YOUR SHELTER FOOTPRINT = Q4 x Q5 x Q6 x 13.26 /Q7	

MOBILITY FOOTPRINT		
Car Travel Subtotal	Your score for Question 8 (Q8)	
	Your score for Question 9 (Q9)	
	Your score for Question 10 (Q10)	
	YOUR CAR TRAVEL SUBTOTAL = Q8 x Q9 x Q10 x 4	
Public Transit Subtotal	Your score for Question 11 (Q11)	
Air Travel Subtotal	Your score for Question 12 (Q12)	
	YOUR MOBILITY FOOTPRINT = Car Travel + Public Transit + Air Travel Subtotals	

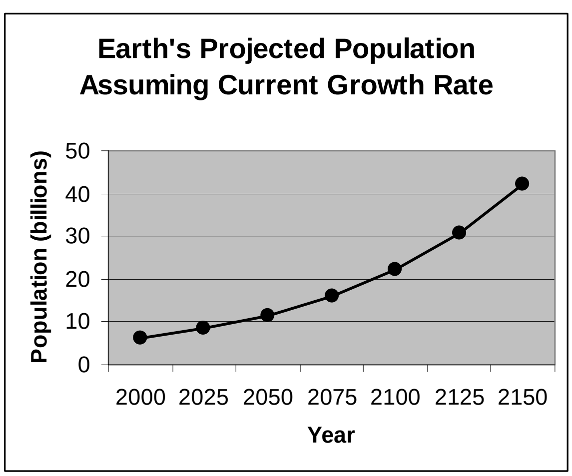
TOTAL ECOLOGICAL FOOTPRINT	
(1) FOOD FOOTPRINT	
(2) SHELTER FOOTPRINT	
(3) MOBILITY FOOTPRINT	
(4) GOODS FACTOR	
(5) SHELTER + MOBILITY: Add (2) + (3)	
(6) GOODS & SERVICES: Multiply (4) x (5) x .9	
Total Ecological Footprint = (1) + (2) + (3) + (6)	

- Your total ecological footprint is the number of global acres needed to provide for your food, housing, transportation, and to account for the amount of waste you produce.

- To calculate the number of earths needed to support your lifestyle, divide YOUR TOTAL FOOTPRINT by 4.5, the number of acres available for each person worldwide.

- The average ecological footprint in the United States is 25 acres per person. Is your footprint higher or lower than the national average?

- Because the worldwide footprint is dependent on the number of people (population) alive today, when the population increases the amount of land available for each person decreases. Look at the population graph below and predict how this will affect the number of acres of land available worldwide over time.



Data source: Redefining Progress http://www.redefining progress.org