CHAPTER 1

Food Science in an Era of Environmental Concern

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Chapter Objectives

THE STUDENT WILL BE EMPOWERED TO:

- Summarize the topics encompassed by the food science discipline.
- Define nutrition ecology, environmental nutrition, sustainable diets, ecosystem services, and ecological footprint—and demonstrate how these concepts relate to the study of food science.
- Provide examples of anthropogenic effects on the natural environment and on food systems.
- Discuss the potential impacts of planetary health, planetary boundaries, climate change, and biodiversity loss on food science, and the potential role of diet in protecting our planetary boundaries and mitigating climate change.
- Discuss current challenges to sustainably feeding the world.
- Explain the concept of nutrition transitions and give examples of global and national transitions currently under way.
- Give specific examples of how the principles of nutrition ecology, environmental nutrition, and sustainable diets can be applied to reduce human impact on the natural environment.

Historical, Cultural, and Ecological Significance of Food Production and Consumption

As biologist and researcher Dr. Martha Crouch has noted, "our relationship with food is the most intimate of all the connections we have with other beings, for we take it into our mouths and actually incorporate it into our cells."[1] Today there are more than 311 million people living in the United States and approximately 7 billion people inhabiting the planet.[2] The global population is expected to increase to more than 9 billion people by 2044.[3] Understanding the projected impact of this population growth on the natural environment is paramount, as human health is inextricably linked to that of the natural environment.[4]

Sustaining human life requires an array of resources, with the most important being food and water. While the simple act of eating and drinking directly connects us to the natural environment at a most basic level, a burgeoning array of scientific data suggests that rapid changes in food production methods, trade, and dietary choices are affecting the living systems of the natural environment at many different levels and in ways not previously experienced. In an era of heightened environmental concern, careful consideration must be given to food- and beverage-related businesses, and to agricultural and lifestyle practices.

This text explores the connections among food, human health, and the natural environment. This introductory chapter broadly examines the natural environment and its relationship to food science.

How the Natural Environment Relates to Food Science

Food science An applied science dedicated to the study of food in terms of the food's physical, biochemical, and chemical nature. The term is all encompassing, including areas such as food processing and the improvement of food for public benefit.

Food science encompasses the investigation of better ways to select, preserve, process, package, and distribute food products. This discipline includes the science of the composition of food ingredients and their manipulation during growing, production, processing, and presentation to the consumer. Therefore, a food scientist must have extensive knowledge on the nature, composition, and behavior of food, such as what happens to its flavor, color, or nutritional properties when cooked or placed in storage.

In this text, we consider food science within the context of the natural world we live in today. Although many of the scientific principles remain the same as for traditional food science, they must be viewed through a new lens when we assume this perspective. To take an "ecological approach," our study of food science must be linked to present-day concerns about food quality, composition, and availability. These factors are all strongly linked to environmental conditions.

Nutrition ecology is defined as an interdisciplinary science that encompasses all aspects of the food chain and the entire nutrition system and its effects on health, the natural environment, society, and the economy.[5] A term coined 25 years ago at the University of Giessen in Germany, nutrition ecology includes the production, harvesting, preservation, storage, transport, processing, packaging, trade, distribution, preparation, composition, and consumption of food—as well as the disposal of waste materials.[5] As part of their endeavors, food scientists now include the work of nutrition ecology and comprehensively consider all links in the nutrition system, including the wholesomeness of food, the sustainability of the natural environment, and food security.[6] (**Special Topic 1.1** covers food security issues in more detail.) Even today, food and nutrition professionals suggest avoiding reductionism in nutrition research and practice,[7] instead encouraging a holistic approach that considers overall dietary patterns[8] and the integrity of food systems.[9]

Special Topic 1.1

Food Insecurity in the United States

Lauren Adler

Modern food science can tell us extraordinary things about the makeup of food and how it keeps us alive and nourished. But what happens when people do not have enough food to consume a healthy diet? While this is sometimes a more serious issue in developing countries, 12.7% of households in the United States experienced food insecurity at some point throughout 2015.[1]

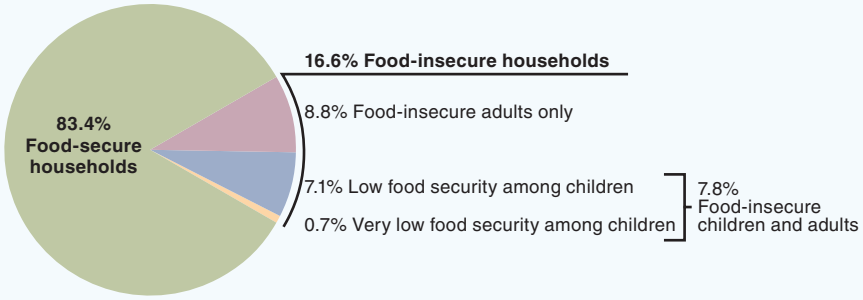
What Is Food Insecurity?

The U.S. Department of Agriculture (USDA) defines *food security* as consistent, dependable access by all household members at all times to enough food for an active, healthy life.[1] **Food insecurity** occurs when households have difficulty at some point providing enough food for all their members due to lack of resources.

Food insecurity The situation in which a household has difficulty providing enough food for all its members due to lack of resources.

Food insecure households fall into two categories depending on degree:

1. *Low food security:* Households with low food security are able to avoid major disruptions by reducing the *kinds* of food they eat.
2. *Very low food security* (formerly called food insecurity with hunger): Households with very low food security have one or more members of the household reduce the *amount* of food they eat; normal eating patterns are disrupted.[1]



U.S. households with children by food security status of adults and children, 2015.

Reproduced from U.S. Department of Agriculture, Trends in food insecurity in U.S. households with children; 2015. Available at: https://www.ers.usda.gov/topics/food-nutrition-assistance/food-security-in-the-us/interactive-charts-and-highlights/

In 2015, 7.1% of U.S. households experienced low food security, and 0.7% of U.S. households experienced very low food security, as shown in the accompanying figure.

How Is Food Insecurity Measured?

In the United States, food security status is measured using a survey called the Core Food Security Module.[2] This module consists of 18 questions (10 for households without children) and is carried out by the USDA using a nationally representative sample. Here are some examples of questions in the survey:

1. "The food that we bought just didn't last and we didn't have money to get more." Was that often, sometimes, or never true for you in the last 12 months?
2. (a) In the last 12 months, did you or other adults in the household ever not eat for a whole day because there wasn't enough money for food? (Yes/No)
   (b) How often did this happen—almost every month, some months but not every month, or in only 1 or 2 months.
3. In the last 12 months, were the children ever hungry but you just couldn't afford more food? (Yes/No)

Who Experiences Food Insecurity?

While a variety of people experience food insecurity, food insecurity is more common in some types of households. The highest rates of very low food security are found in the following households See Figure ST 01B:

- Households with incomes below the poverty line
- Families with children, headed by single women

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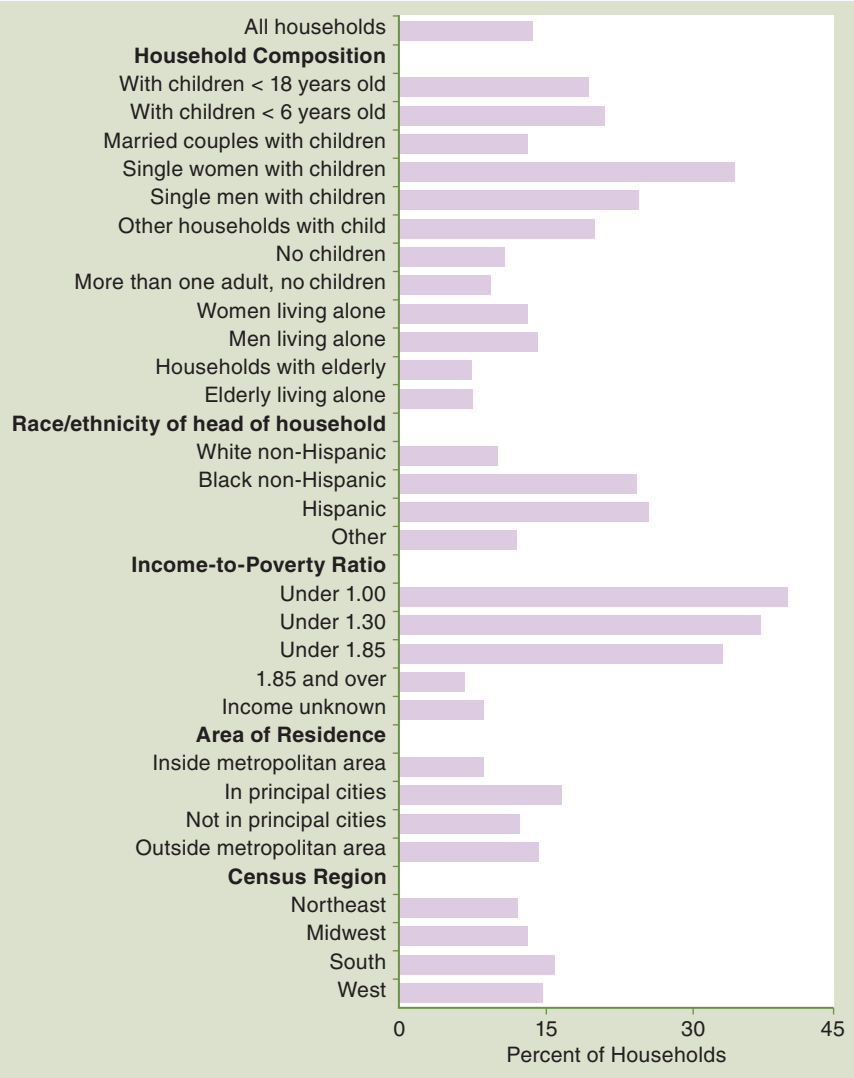

Percentage of U.S. households reporting indicators of food insecurity.

Modified from Coleman-Jensen A, Nord M, Andrews M, Carlson S. Household Food Security in the United States, 2010 (Figure 4). Washington, DC: U.S. Department of Agriculture, Economic Research Service; 2011.

- African American households
- Hispanic American households
- Families with children, headed by single men
- Households in principal cities of metropolitan areas[1]

Food assistance programs were implemented by the U.S. government to help Americans combat food insecurity.[2] These initiatives include the Supplemental Nutrition Assistance Program (food stamps); Women, Infants, and Children; National School Lunch Program; National School Breakfast Program; and Emergency Food Assistance Program. These programs, along with community efforts such as soup kitchens and community volunteers, help to increase food security throughout the United States.

References

1 Nord M, Coleman-Jensen A, Andrews M, Carlson S. *Household food security in the United States, 2009*. Vol 108. Washington, DC: U.S. Department of Agriculture, Economic Research Service; 2010.

2 Edelstein S, Gerald B, Crutchley Bushell T, Gundersen G. *Food and nutrition at risk in America: food insecurity, biotechnology, food safety, and bioterrorism*. Sudbury, MA: Jones and Bartlett; 2009.

Another whole systems framework is *environmental* nutrition.[10] Environmental nutrition is defined as "the public health impacts of the social, economic, and environmental factors related to the entire food system."[10] Environmental nutrition carefully considers the benefits and risks of the entire food system.[10] In this way the environmental impact, social injustices, health risks, and total economic impact of food and the food system can be adequately understood and addressed.[10]

Additionally, the Food and Agriculture Organization of the United Nations defines *sustainable diets* as those diets with low environmental impacts that contribute to food and nutrition security and to healthy life for present and future generations.[11] Sustainable diets are protective and respectful of biodiversity and ecosystems.[11] They are culturally acceptable, accessible, economically fair, and affordable.[11] Sustainable diets are nutritionally adequate, safe, and healthy—while optimizing natural and human resources.[11]

Ecological Literacy

Collectively, our understanding of the interconnected systems that provide food and sustain the web of life is known as **ecological literacy**.[12] The following terms are important to this understanding:

- An **ecosystem** is a dynamic complex of plant, animal, and microorganism communities, as well as the nonliving environment that interacts and functions as a unit.[13]
- *Ecosystem services* are the benefits that people obtain from ecosystems, including food and water; the regulation of floods, drought, land degradation, and disease; soil formation and nutrient cycling; and cultural, recreational, spiritual, religious, and other nonmaterial benefits.[13]
- **Living systems** are the animate, interconnected components and processes of ecosystems (no matter how small or large) that continuously affect and depend on each other as well as the integrity of the system.[13] The principles of living systems include interdependence, systems integrity, feedback, biodiversity, cooperation and partnership, living cycles, optimal size, and waste equals food.[14]

Ecological literacy An understanding of the interconnected systems and associated relationships that sustain the web of life.

Ecosystem A dynamic complex of plant, animal, and microorganism communities, as well as the nonliving environment, whose components interact and function as a unit.

Living systems The animate, interconnected components and processes of ecosystems (no matter how small or large) that continuously affect and depend on one another as well as the integrity of the system.

The Current Need for an Ecological Approach

Numerous scientific reports and research studies have documented the degradation of the natural environment and the decline of ecosystems. The past 50 years of human activity has "altered ecosystems to an extent and degree unprecedented in human history."[15] Ecological systems are experiencing multiple severe and mutually reinforcing stresses.[15] The root causes of ecosystem changes are the increased per-person consumption of ecosystem services and a growing population.[15] Among others, the following trends will continue to disturb ecosystem functions: [15]

- Increased demand for food, fiber, and water
- Introduction of ecosystem contaminants and production of waste
- Eutrophication of waterways
- Global trade
- Climate change
- Over-fishing, over-grazing, and over-logging
- Habitat loss and fragmentation

Another trend that may disturb ecosystem function is the introduction of genetically modified crops and other food species into the natural world. Genetic manipulation of our food supply may have unintended consequences, as discussed in **Special Topic 1.2**.

Special Topic 1.2

Genetically Modified Organisms and Food

Jeannie Houchins, MA, RD

Genetically modified organisms (GMOs) are increasingly present in our food supply. Each country handles this technology and its end products differently. Even definitions vary slightly between the United States and the World Health Organization (WHO):

Genetically modified organisms (GMOs) Plants or animals that have altered DNA that does not occur naturally in nature. Can also be known as genetically modified food (GMF) or genetic food (GF).

- According to the U.S. Department of Energy Genome Programs, **genetically modified organisms (GMOs)** are those that have been transformed by the insertion of one or more transgenes (genes not naturally found in the organism).
- According to WHO, GMOs are organisms in which the genetic material (DNA) has been altered in a way that does not occur naturally.

The terms *biotechnology* and *genetic modification (GM)* are commonly used interchangeably by the press; however, biotechnology is a more general term that refers to using organisms or their components—such as enzymes—to make products such as wine, cheese, beer, and yogurt (as well as various nonfood products).[1] GM, in contrast, refers to a specialized set of technologies that alter the genetic makeup of organisms such as animals, plants, or bacteria.

GM technology is also called "modern biotechnology," "gene technology," "recombinant DNA technology," and "genetic engineering." GM technology allows selected individual genes to be transferred from one organism into another, and also between nonrelated species. Such methods are used to create GM plants—which are then used to grow GM food crops. As with many scientific innovations, there are both benefits and controversies associated with GMOs.

Perceived Benefits[1]

Crops

- Enhanced taste and quality
- Reduced maturation time
- Increased nutrients, yields, and stress tolerance
- Improved resistance to disease, pests, and herbicides
- New products and growing techniques

Environment

- "Friendly" bioherbicides and bioinsecticides
- Conservation of soil, water, and energy
- Bioprocessing for forestry products
- Better natural waste management
- More efficient processing

Society

- Increased food security for growing populations

Perceived Controversies[1]

Ethics

- Violation of natural organisms' intrinsic values
- Tampering with nature by mixing genes among species
- Objections to consuming animal genes (and their products) in plants, and vice versa

Environment and Health

- Potential environmental impacts, including unintended transfer of transgenes through cross-pollination, unknown effects on other organisms (e.g., soil microbes), and loss of flora and fauna **biodiversity**
- Potential human health impacts, including allergens, transfer of antibiotic resistance markers, and unknown effects

Labeling

- Not mandatory in some countries (e.g., United States)
- Mixing GM crops and non-GM ingredients in food products, which confounds labeling attempts

Society

- New advances that may be skewed to the interests of rich countries
- Domination of world food production by a few companies
- Increasing dependence by developing countries on industrialized nations
- Biopiracy, or foreign exploitation of natural resources

Biodiversity The variety of life forms that make up a community, including plants, animals, fungi, and microorganisms. In recent years, this term has come to stand for the concepts and principles of conservation.

Herbicide A type of pesticide used to kill unwanted plants such as weeds. Herbicides target a specific type of plant while leaving all others, including the growing crop, alone. Plants can produce natural herbicides in reaction to an encounter with an undesirable species or substance.

According to WHO, GM foods are developed and marketed because they offer some perceived advantage either to the producer or the consumer of these foods that translates into a product with a lower price or a greater benefit (in terms of durability or nutritional value), or both.[2] Initially, GM seed developers wanted their products to be accepted by producers, so they concentrated on innovations that farmers (and the food industry more generally) would appreciate.[2] The initial objectives for GM plants were to improve crop protection (through the introduction of resistance against plant diseases caused by insects or viruses) or to increase crop tolerance to **herbicides**.[2]

The question of whether GM foods are safe is one that WHO takes seriously. WHO has created parameters to assess the safety of GM foods, including the investigation of the following aspects of their use[2]:

- Direct health effects (toxicity)
- Tendencies to provoke allergic reaction (allergenicity)
- Specific components thought to have nutritional or toxic properties
- Stability of the inserted gene
- Nutritional effects associated with genetic modification
- Any unintended effects that could result from the gene insertion

Environmental risks are of particular concern with GM products. The WHO assessment process includes evaluation of a GMO's stability in the environment. This assessment considers both ecological characteristics of the environment in which the introduction will take place and the potential unintended effects that may result from the insertion of the new gene.[2]

According to WHO, GM foods currently available on the international market have passed risk assessments—they are not likely to present risks to human health. Furthermore, no effects on human health have been shown to result from the consumption of GM foods by the general population in the countries where they have been approved.[2] Risk assessments based on the Codex principles and active food monitoring are the basis for evaluating the safety of GM foods.[2] The food regulations implemented by each government vary; countries with provisions for GM foods usually also regulate GMOs and generally take into account health and environmental risks, as well as control- and trade-related issues (such as labeling). In view of the dynamics of the debate on GM foods, legislation is likely to continue to evolve.[2]

References

1 U.S. Department of Energy, Office of Science. Human Genome Project information, genetically modified foods and organisms. http://www.ornl.gov/sci/techresources/Human_Genome/elsi/gmfood.shtml. Accessed August 20, 2017.

2 World Health Organization. Frequently asked questions on genetically modified foods. http://www.who.int/foodsafety/publications/biotech/20questions/en/index.html. Accessed August 20, 2017.

Biocapacity The regenerative capacity and the availability of natural resources of the planet.

Anthropogenic effect An effect created by or caused by human activity.

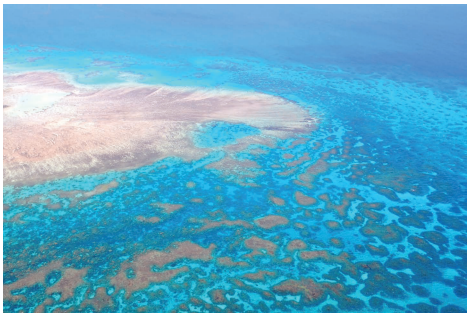

FIGURE 1.1 Natural resources such as the ocean are at risk.

FIGURE 1.2 The health of the world's oceans is declining as a result of over-fishing. Because no one country or person owns the ocean's resources, they are open to exploitation by everyone. If there are no limits on fishing, certain fish populations will collapse.

Human demands on the biosphere more than doubled between 1961 and 2007.[16] An assessment of renewable resource utilization revealed that humans have exceeded the Earth's biocapacity by 50%.[16] **Biocapacity** represents the regenerative capacity and the availability of the natural resources of the planet. Even using modest projections, the calculations point to a situation defined as "ecological overshoot."[17] That is, humans are using ecosystem resources faster than they can be replenished in one year. According to the Global Footprint Network, "humanity exhausted nature's budget of natural resources for the year on August 8, 2016"—a day this organization now calls "Earth Overshoot Day."[18] In the previous year, Earth Overshoot Day was on August 13, 2015.[19]

Ecosystem health and ecosystem services are deeply affected by food production and acquisition methods, food consumption patterns, and other **anthropogenic effects**—that is, the effects caused by human activities. Some suggest that the U.S. Farm Bill should mandate an Environmental Impact Statement that encourages farmers and other food producers to decrease the ecological degradation associated with food and agricultural practices.[20] As an example, a closer examination of aquatic ecosystems—oceans, rivers, and lakes—illustrates the concern:

- Systemic over-fishing of inland fresh waters has been shown to threaten biodiversity.[21]
- Populations of the North Atlantic basin's diadromous fish—those species that migrate between saltwater and freshwater—have suffered dramatic declines due to habitat loss, over-fishing, pollution, and the negative effects of climate change, non-native species, and aquaculture.[22]
- Anthropogenic coal emissions have been implicated in increasing levels of methyl mercury in fish to a level hazardous to human consumers.[23,24] See **Figure 1.1** and **Figure 1.2** that address these issues.

Table 1.1 lists—for each major category of food—some of the issues studied by food scientists.

How This Affects the Study of Food Science

- Eating lower on the food chain can decrease the impact on the natural environment.
- Eating local foods can reduce the impact on the natural environment.
- Organically grown foods can reduce the impact on the natural environment.

Planetary Health

Because the health of the natural environment and the health of human beings cannot be separated, the concept of *planetary health* offers a vision and framework that comprehensively and simultaneously considers both.[25] Planetary health can be defined as achieving the highest attainable standard of human health and well-being that is equitable to all individuals while safeguarding the limits of the natural environment.[25] The connections between human health and the natural environment involve a multitude of interrelated systems that also traverse our constructed political, economic, and social systems with the capacity to both improve and undermine planetary health.[25]

TABLE 1.1
Relationship of Food Science to the Natural Environment

Food Science Categories	Examples
Meat	1. Effects of animal feed on meat composition 2. Overuse of antibiotics leading to antibiotic resistance 3. Pesticide residues in animal feed and meat tissue
Fish	1. Impacts of over-fishing changes on ecosystem services 2. Contamination of wild fish populations by aquaculture species 3. Antibiotics used in aquaculture showing up in food supply
Poultry	1. Microbial contamination that affects human consumption 2. Overuse of antibiotics and hormones 3. Avian flu
Milk and dairy products	1. Bovine growth hormone 2. Contaminants in milk and food safety 3. Antibiotic use
Eggs	1. *Salmonella* contamination 2. The relationship between asthma and egg allergy in the pediatric population 3. Higher levels of microbial contamination in unwashed eggs
Fruits and vegetables	1. Pesticide residues 2. Importing fruit year-round, which increases the distance traveled and contributes to greenhouse gas emissions 3. Ability to transport food over far distances, which may alter the picking time and can affect the flavor and nutrient content
Grains	1. Pesticide use and content in grain products 2. Effects that grains fed to animals can have on meat composition 3. Desertification of cropland—effects on grain crop size and quality
Fats and oils	1. Effects of monoculture growing environments and genetically modified organisms (GMOs) 2. Effects of chemicals used in processing 3. Effects of using food crops for biofuels
Nuts	1. Pesticide residues in nuts 2. Nut composition and food allergies 3. Waste practices
Sugar	1. Human health implications (e.g., effects of high-fructose corn syrup) 2. Destruction of native ecosystems, water contamination, and other ecosystem disturbances resulting from burning waste after harvest with certain sugar crops 3. The large amounts of environmental energy involved in processing sugar
Sugar replacements	1. Potential health risks associated with sugar replacements' composition 2. Contamination of groundwater, manure, and sewage sludge during production
Water	1. Large amounts needed to support livestock 2. Effects of climate change on water supplies 3. Groundwater contamination
Food preservation	1. Nanotechnology and human health 2. Effects of certain food additives on human health 3. Food safety concerns (home canning; irradiation)
Food packaging and waste	1. Leaching of food packaging chemicals into food and liquids 2. Excessive and unnecessary use of disposable food packaging 3. Expanding food composting services

Modified from Science.gov. Earth science applications.

Special Topic 1.3

USDA's Biobased Product Label

Katrina Schroeder

Today's educated consumers are constantly on the lookout for products that will help them "do the right thing." Is a product organic? Was it sourced from sustainable material? Is it made in the United States? Were the workers treated fairly? Concern for the environment as well as concerns about U.S. dependence on foreign materials such as oil and petroleum has led many people to ask these questions, among others, when purchasing items ranging from pet food to packaging materials.

The USDA's new BioPreferred program aims to make shopping decisions easier through the new USDA Certified Biobased Product label,[1] shown here. Companies must apply to use the label by submitting proof to the USDA that their product is biobased.

Biobased product A product that has been engineered from a food source for another use, such as ethanol made from corn.

A **biobased product** is a commercial or industrial product or package made of at least 25% biological products, renewable agricultural materials (including plant, animal, and marine materials), or forestry materials. This definition was put into place by the 2002 Farm Bill and was revised in the 2008 Farm Bill to include intermediate ingredients or feedstocks as biobased products.[2] The label indicates what percentage of the product is biobased and whether it is the product itself or the packaging (or both) that is made from the renewable biological products.

The label also indicates whether a biobased product is part of the federal procurement preference program. These products will have the letters "FP" on the label in addition to the percentage. The BioPreferred program requires federal agencies to give preference to biobased products when making certain purchases.[3]

Numerous types of products are eligible for the new label (for a full list of products that are currently approved to bear the label, see the catalog at https://www.biopreferred.gov/BioPreferred/faces/catalog/Catalog.xhtml). Some examples of product categories are toiletries, office supplies, vehicle maintenance products, industrial products, and pet supplies. Examples of products that have been approved to carry the USDA Certified Biobased product label include Pain Relief Massage Cream from Botanical Skin Works, Biodegradable Mechanical Pencil with Grip by Papermate, and Living Fresh Towels from Valley Forge Fabrics.

With all new initiatives comes concern about their effectiveness. A USDA press release dated January 19, 2011, indicated that the "growing [biobased] industry as a whole is responsible for over 100,000 jobs" and that the initiative will create green jobs and new markets for farmers. Agriculture Deputy Secretary Kathleen Merrigan says:

> Today's consumers are increasingly interested in making educated purchasing choices for their families. This label will make those decisions easier by identifying products as biobased. These products have enormous potential to create green jobs in rural communities, add value to agricultural commodities, decrease environmental impacts, and reduce our dependence on imported oil.[1]

However, as one article on *Sustainablog* points out, there is no requirement that the biobased materials come from American farmers or even be American made.[4] In fact, imported products are eligible for the label as long as they adhere to the same standards of testing as U.S. products. Another issue is consumer confusion; some might think that the USDA's new label is an endorsement of sorts, and the term "biobased" can be confused with terms like "green" and "organic." According to the USDA website's FAQs about the label, the environmental benefit of purchasing these products is not entirely clear. When asked if these products are better for the environment, the answer is:

> A USDA Certified Biobased label is not a guarantee or expression of environmental preferability or impact. There is an expectation that the increased use of biobased products will help reduce petroleum consumption by increasing the use of renewable resources, thus reducing the amount of new carbon released into the atmosphere, helping to better manage the carbon cycle, in turn reducing resultant adverse environmental and health impacts.[5]

At this time consumers may be hard-pressed to find this label on any products. A few reasons might explain this scarcity. The USDA takes up to 60 days to approve or reject an application—a time frame it hopes to shorten as the project picks up steam.[5] When you consider that the labeling initiative started in January 2011 and the products must first be tested before the application can be submitted, it is not a big surprise that there are not currently a lot of labeled products on the market. Also, the cost of testing a single product to prove biobased status and percentage is estimated by the USDA at approximately $600 per product.[5] It is possible that a company that manufactures biobased products will not see the cost benefit of paying for testing to obtain a label that has not been proven to create more demand for a product. There is currently no financial assistance available for this testing from the USDA; it is hoped that increased demand for testing will drive down the price over time.[5]

If the biobased product movement gains momentum, more and more products will begin to display the label. Consumers will then be able to make more educated purchases based on the percentage of biobased material in the product or packaging they choose to buy.

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1 U.S. Department of Agriculture. News release: USDA launches new biobased product label to boost demand for products made from renewable commodities and support green jobs. http://www.usda.gov/wps/portal/usda/usdahome?contentid=2011/01/0015.xml&navid=NEWS_RELEASE&navtype=RT&parentnav=LATEST_RELEASES&edeployment_action=retrievecontent. Accessed December 2, 2016.

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Planetary Boundaries

The biological processes of the Earth play a crucial role in the processes of maintaining the Earth's stability. However, human activity has impeded these natural processes.[26] The *planetary boundaries* framework offers a way to encapsulate how human activity is affecting the totality of the Earth system.[27] By quantifying the dynamic, interconnected, and intricate processes of the Earth system, scientists can identify the conditions that maintain or jeopardize humanity's safe operating space on the planet.[27] The nine planetary boundaries include climate change, biosphere integrity (including biodiversity), land-system change, freshwater use, biochemical flows (nitrogen and phosphorus overuse), ocean acidification, atmospheric aerosol loading, stratospheric ozone depletion, and novel entities (persistent chemical pollution).[27] **Figure 1.3** demonstrates the status of seven planetary boundaries.

The green areas in the center of the diagram denote the "safe zones" of these respective boundaries, whereas the yellow areas indicate an increasing risk of uncertainty seen with climate change and land-system changes.[27] The red zones denote areas of high risk, as seen within the boundaries of biosphere integrity (biodiversity loss) and biochemical flows (excessive amounts of nitrogen and phosphorus in the natural environment). Scientists are still working to quantify certain boundaries, as indicated by the question marks.[27] From this diagram we can visualize and better understand the role of food choices and food systems in impacting our planetary boundaries.

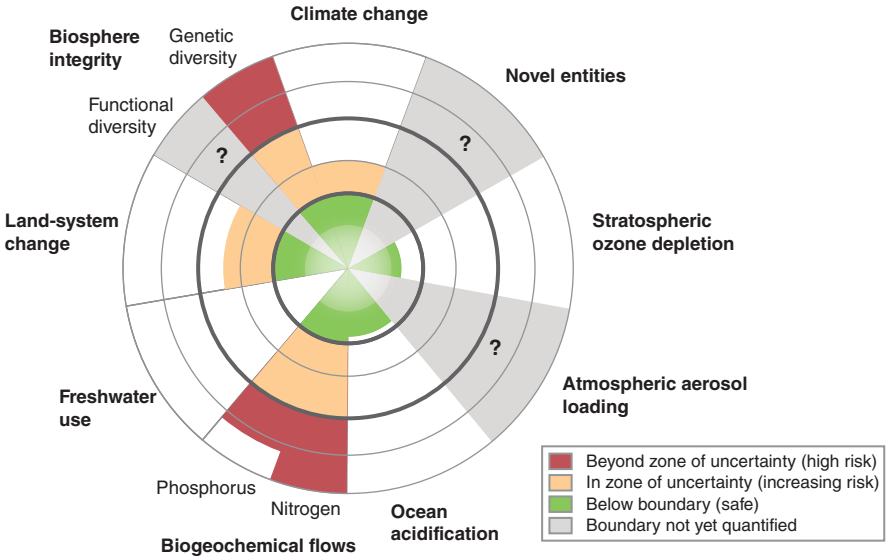


FIGURE 1.3 The Current Status of the Control Variables for Seven of the Planetary Boundaries.

Graphic reprinted with the permission of Dr. Will Steffen. *Science*, 2015, 347, 1259855.

Biodiversity Loss

Attention to and the correction of biodiversity loss are critical, as biodiversity loss is considered the most concerning aspect of the environmental crisis.[28] Often referred to as the planet's "life support system," biodiversity is the entirety of the living beings and organisms on the planet and their ecological systems.[28,29] It is characterized by genetic, species, and ecosystem diversity.[30] Biodiversity and ecosystems offer countless essential services (ecosystem services), including pollination; air quality, climate regulation, and natural hazard regulation; water purification; erosion, pest, and infectious disease control; and the obvious necessities of provisioning food, medicines, and shelter.[13,31] While extinction is thought to be a normal process within the Earth system,[32] the anthropogenic destruction of biodiversity has occurred at an accelerated rate such that current levels of extinction far exceed background rates; this trend has been dubbed "The Sixth Mass Extinction."[28] In the past 40 years alone, populations of mammals, birds, reptiles, and amphibians have declined by an alarming 52%.[33] Fish species declined by 49% between 1970 and 2012.[34] Approximately 52% of global fish stocks are considered fully exploited, with 17% being overexploited.[35]

The types of human and broad-scale agricultural activity that drive biodiversity loss and ecosystem changes include, but are not limited to, changing or destroying habitats, degrading coral reefs, climate change, pollution, and the gross exploitation of natural resources and animals.[13,31] Additionally, degrading biodiversity and ecosystems in an era of climate change is highly problematic because climate change and biodiversity loss are reinforcing stressors that diminish ecosystem resilience and the ability to withstand system changes.[36,37] The more biodiverse ecosystems are, the more resilient and stable they are.[37] Conversely, biodiversity loss reduces productivity and the efficiency of ecological communities.[36]

The Convention on Biological Diversity is a global working agreement recognizing that biodiversity underpins the essential services for human well-being and poverty alleviation.[38] Its six strategic goals include 20 defined targets, such as the following:[39]

- **Target 1:** By 2020, at the latest, people are aware of the values of biodiversity and the steps they can take to conserve and use it sustainably.
- **Target 3:** By 2020, at the latest, incentives, including subsidies, harmful to biodiversity are eliminated, phased out, or reformed in order to minimize or avoid negative impacts, and positive incentives for the conservation and sustainable use of biodiversity are developed and applied, consistent and in harmony with the Convention and other relevant international obligations, taking into account national socioeconomic conditions.
- **Target 4:** By 2020, at the latest, governments, business, and stakeholders at all levels have taken steps to achieve or have implemented plans for sustainable production and consumption and have kept the impacts of use of natural resources well within safe ecological limits.
- **Target 5:** By 2020, the rate of loss of all natural habitats, including forests, is at least halved and where feasible brought close to zero, and degradation and fragmentation is significantly reduced.
- **Target 8:** By 2020, pollution, including from excess nutrients, has been brought to levels that are not detrimental to ecosystem function and biodiversity.

May 22 has been declared an international day for the recognition of biodiversity. The 2017 theme was entitled "International Year of Sustainable Tourism for Development."[40]

Effects of Climate Change

With evidence of consensus among U.S. scientists and numerous intergovernmental scientific reports, declarations, protocols, and working groups, *climate change*—also called atmospheric warming or global warming—is a pressing environmental concern.[41,42] Anthropogenic carbon dioxide emissions have been linked to increasing temperatures and irreversible, adverse changes to climate that are projected to stress the living beings and the living systems of this planet.[43]

The year 2016 was the warmest year on record, surpassing the most recent record set in 2015.[44] As this trend appears poised to continue, the need for global, regional, and individual actions to mitigate climate change is imperative. Climate change encompasses variations in the climate attributed to human activity that alters the global atmosphere.[45] These changes become clear when we take a longer view. As an example, **Figure 1.4** demonstrates the increase in global temperatures since the 1880s.[46]

These climate changes may have a variety of effects[43]:

- Alter rainfall patterns, adversely affecting the supply of water for humans, agriculture, and ecosystems
- Increase the frequency of fire and desertification
- Raise sea levels, flooding arable land currently located near coastlines

Climate change also changes ocean chemistry in ways that may greatly affect biodiversity and ecosystem services, as well as the fishing industry. If carbon dioxide emission trends continue, the ocean will continue to undergo acidification, to an extent and at rates that have not occurred for tens of millions of years.[47] **Acidification** occurs when carbon dioxide is absorbed by oceans. It changes the chemistry of the sea, which can impair marine life and may adversely affect the food web. Such changes compromise the long-term viability of marine ecosystems—such as coral reefs (**Figure 1.5**)—and the associated benefits they provide, including coastland protection from storm surges.[47] Coral reefs are also threatened

Acidification Absorption of carbon dioxide by the oceans, which changes the chemistry of the sea; it can impair marine life and may adversely affect the food web.

FIGURE 1.5 Climate change is one of the biggest threats to the Great Barrier Reef off the coast of Australia. Increasing ocean temperatures cause coral bleaching, whereby the coral stop producing their brightly hued pigments. This trend also leads to increased disease susceptibility, which negatively affects the ecology of the reef community.

FIGURE 1.6 The global carbon cycle is the biogeochemical cycle by which carbon is exchanged among living organisms, the soil, rocks, water sources, and the atmosphere. Through the carbon cycle, carbon is recycled throughout the biosphere and all of its organisms.

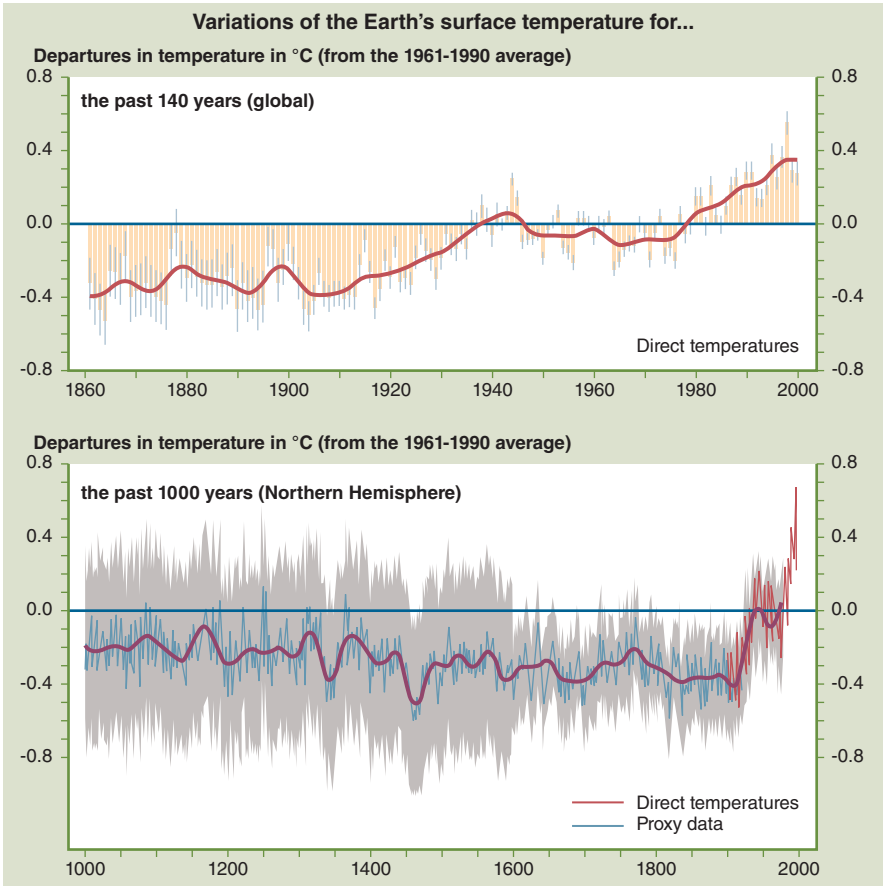


FIGURE 1.4 NASA map of the world depicting changes in the Earth's temperatures. These maps depict surface temperatures across the world in the 1880s (left) and the 1980s (right). The blue colors represent cooler temperatures, and the red colors indicate warmer temperatures. The Earth's average surface temperatures have increased since 1880, with two-thirds of the warming occurring after 1975.[46]

Reproduced from U.S. Department of Agriculture, Trends in food insecurity in U.S. households with children; 2015. Available at: https://www.ers.usda.gov/topics/food-nutrition-assistance/food-security-in-the-us/interactive-charts-and-highlights/

by coastal development, pollution, exploitation, and destructive fishing practices.[47] Recommendations for improving the health of these ecosystems include limiting fossil fuel emissions and managing the resilience of marine ecosystems until they have recovered from the impacts of climate change.[47]

Additionally, studies conducted in the North Pacific and the North Atlantic reveal unexpectedly large changes in deep-ocean ecosystems due to climate-driven changes.[48] Climate change not only affects oceanic surface waters and the deep sea, but also disrupts the global carbon cycle (**Figure 1.6**), which will likely influence the ecology and biogeochemistry of the deep sea.[48]

Models of climate change in the United States predict that crop and livestock production will be increasingly challenged due to pests, water limitations, diseases, and weather extremes, while the nutrient composition of foods may be altered.[49] These effects are detailed in **Special Topic 1.4**. Humans will face increased health risks relating to heat stress, waterborne (and insect-borne and rodent-borne) diseases, poor air quality, and extreme weather events.[49] Numerous interconnected social and environmental stresses

Special Topic 1.4

The Effects of Climate Change on the Earth's Food Supply

Lauren Levandowski

Since the beginning of the industrial era, human activity has increased the amount of carbon dioxide (CO_2) in the atmosphere, which has influenced significant changes in global weather patterns and temperatures.[1] Large amounts of CO_2 and other so-called greenhouse gases emitted by human activities absorb heat, trapping it in the atmosphere and causing a **greenhouse effect**. This is a naturally occurring process, but it has been substantially increased by the amount of CO_2 being emitted into Earth's atmosphere. In the United States, the burning of fossil fuels in power plants and in automobiles, industrial and agricultural processes, and waste management practices are all major sources of greenhouse gases.

Electricity generation is the greatest source of these emissions in the United States, followed by transportation.[1]

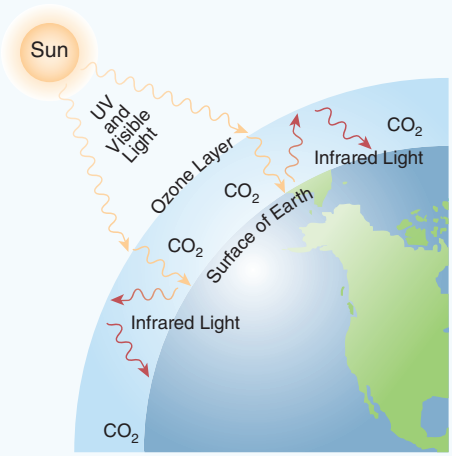
Greenhouse effect The result of gas emissions caused by human activities trapping heat in the atmosphere. This naturally occurring process has been substantially increased by the amount of carbon dioxide being admitted into Earth's atmosphere.

Crop yield Agricultural output; a measure of the amount of a crop harvested per unit over a given time. This term can be used to refer to not only the crop as a whole, but also the size of an individual plant.

Climate Change and Agriculture

In general, climate change may benefit food production in many regions that have a cool spring and fall, by creating a warmer climate and a longer growing season. However, crop production will be reduced in areas where summer temperatures already limit plant growth. Because plants use carbon dioxide in photosynthesis, higher levels of atmospheric carbon dioxide may have a positive effect on many crops, potentially increasing **crop yields**. However, studies have shown that optimizing plant growth through increased levels of CO_2 will not increase nutritional qualities, such as protein concentrations, in proportion to the higher crop yields.[2]

Climate change is also likely to increase the frequency and severity of natural disasters—such as droughts, floods, and extreme heat waves—that have devastating effects on crop production. Additionally, increased temperatures over time may alter water supplies by evaporating soil moisture, making the continued production of crops in certain regions of the world unrealistic. Rising temperatures will also increase the ability



Greenhouse gases account for only 1% of the atmosphere, but they regulate Earth's climate by trapping heat. As the amount of atmospheric greenhouse gases increases, global temperatures increase, too.

(*continues*)

Livestock raised for human food consumption is a major source of greenhouse gases, which includes 37% of anthropogenic methane emissions, 65% of anthropogenic nitrous oxide emissions, and 64% of anthropogenic ammonia emissions.
© LUGO/iStockphoto.com

of agricultural pests to survive what were traditionally harsh winters, allowing them to attack spring crops.[2] According to the U.S. Environmental Protection Agency, agriculture production is very sensitive to climate variability and extreme weather patterns. An increase in the frequency of heat stress, floods, and droughts negatively affects crop yields and livestock production beyond any positive impacts of climate change.[1]

Lastly, rising temperatures are shrinking the amount of Arctic sea ice; currently roughly half of the ice coverage is left, compared to measurements taken in 1979. This melting sea ice contributes to the rising sea levels observed around the world. Some of the key concerns associated with rising sea levels include loss of land (some of which may be used for food production), increased risk of flooding, and increased salinity in coastal water supplies.

The Future of the Food Supply

The greatest loss of usable cropland is likely to occur in Africa and parts of South Asia, whereas the largest gains of suitable cropland will be in Russia and Central Asia.[2] The variations in global and regional weather patterns will bring greater fluctuations in crop yields, consequently decreasing food supply stability and overall food security. Regions currently experiencing the highest levels of undernourishment—found in parts of Africa and South Asia—are the same regions predicted to have the most dramatic drop in crop yields.[2]

Climate change may also increase the prevalence of food- and water-borne diseases. For example, warmer temperatures may increase humans' risk of food poisoning from shellfish and reef-fish. Higher temperatures may also hinder the ability to safely store food products in areas with traditionally temperate climates. Increased flooding, especially in regions with insufficient sanitation practices, will increase the number of people at risk of water-borne diseases.

Climate change increases the risk of flooding because warmer air holds more moisture. Scientists predict that the amount of rain in the heaviest precipitation events will increase by more than 40% by 2100, increasing the risk of catastrophic floods.
Courtesy of USDA. Photograph by Lance Cheung.

Global warming is making droughts more severe in semiarid and subhumid regions in parts of Africa, Asia, and North America.
Courtesy of USDA.

Wind power is a renewable, clean energy source that does not result in the release of greenhouse gases into the atmosphere. Development of alternative energy sources such as wind, solar, and tidal energy will decrease the release of greenhouse gases and possibly decrease the rate of climate change.
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Overall, research has shown that global warming/climate change will affect food availability by impacting food production and trade, access to food, stability of food supplies, and food utilization. Within much of the developing world, the adverse impacts of climate change will be felt disproportionately by the poor.[2] In many of these regions, farmers have little ability to adapt to the changing conditions.

For the U.S. and world agriculture industries, their fate depends on their ability to adapt to these changes through new technology and sustainable, environmentally friendly agricultural practices. Adapting to changing growing seasons and altering crops to make them better suited to the changing conditions will be necessary.[1] Developing and employing clean energy sources, such as wind and solar energy, will also decrease reliance on fossil fuels and the production of greenhouse gas emissions. These steps have the potential to protect and improve the future of the food supply and the environment.

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2 Schmidhuber J, Tubiello FN. Global food security under climate change. *PNAS*. 2007;104:19703-19708. http://www.pnas.org/content/104/50/19703.full.pdf. Accessed August 17, 2017.

will also increase, especially when the effects of climate change are combined with pollution (**Figure 1.7**), population growth, the overuse of resources (**Figure 1.8**), increased urbanization, and economic stressors.[50]

Mitigating Climate Change

Intergovernmental, national, and municipal organizations continue to strive to meet the challenge of creating substantive policies to mitigate climate change. In this struggle, they are joined by the advocacy and research efforts of nongovernmental organizations, academic institutions, and nonprofit groups, including religious organizations. In particular, the United Nations (UN) Millennium Development Goals are based on the UN's compilation of the priority needs of those people living in the poorest countries. Climate change is predicted to most severely impact those persons with the fewest resources, even though they have contributed the least to the anthropogenic degradation of the natural environment.[50] One of the UN goals targets environmental sustainability, focusing on the following concerns:[50]

- Integrating sustainability into all levels of policies and programs
- Reversing the loss of natural resources
- Reducing biodiversity loss
- Increasing access to safe drinking water and basic sanitation
- Improving the lives of slum dwellers[50]

In the United States, the Centers for Disease Control and Prevention (CDC) has created a climate and health program providing a framework for states, health departments, and communities to build capacity and anticipate problems related to climate change.[51] The National Institutes of Health also seeks to increase research and partnership opportunities to minimize the impacts of climate change on human health.[52] *Healthy People*, the United States' set of strategic evidence-based health objectives (defined over a 10-year period), states that the health of all is promoted through a healthy environment (**Figure 1.9**).[53] The *Healthy People 2020* environmental health objectives focus on six themes: outdoor air quality, surface and ground water quality, toxic substances and hazardous wastes, homes and communities, infrastructure and surveillance, and global environmental health. In addition, "emerging issues" include climate change, disaster preparedness, nanotechnology, the built environment, exposure to unknown hazards, and blood lead levels.[53] On a

FIGURE 1.7 Los Angeles, California, is well known for its smog. Increasing global temperatures will only worsen smog in such areas, increasing the number of days per year when ozone concentrations exceed federal clean air standards, affecting the health of millions of people.

FIGURE 1.8 The Colorado River is an important source of freshwater for a number of Western states. Increased demand coupled with rising temperatures due to global climate change increases the risk of this valuable resource drying up.

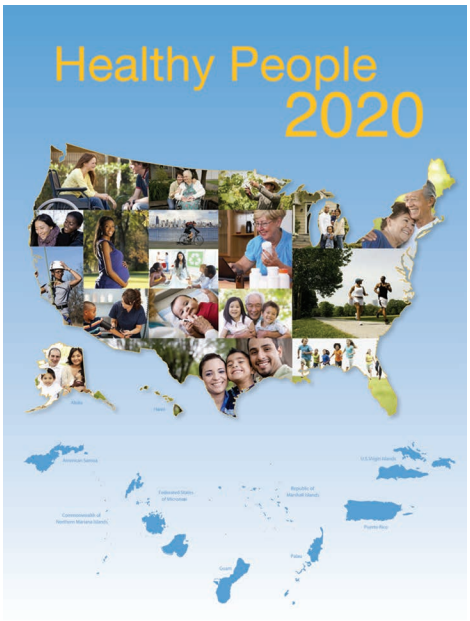

FIGURE 1.9 One of the goals of *Healthy People 2020* is to promote health for all Americans through a healthy environment.

Courtesy of HealthyPeople.gov, U.S. Department of Health and Human Services.

Ecological footprint An estimate of the amount of land and ocean required to support a person's consumption of food, goods, services, housing, and energy and to assimilate waste.

Green Point

Based on experimental modeling, following certain dietary practices (consuming plant-based diets, in particular) has been found to be an effective way to decrease greenhouse gas emissions and feasibly achieve climate stabilization goals.[66] Furthermore, plant-based diets are nutritionally sound throughout the entire life cycle, and can reduce chronic disease morbidity.[74]

global scale, one-fourth of all deaths are linked to environmental factors,[54] so attention to the interface between humans and the natural environment is paramount to improving and protecting public health.

Despite the complexities and challenges of climate change, governments, businesses, and citizens alike must aggressively reduce greenhouse gas emissions now and into the future to help mitigate the negative impacts of irreversible climate change. On Earth Day 2016 (April 22, 2016), leaders representing many worldwide countries signed the historic Paris Agreement with the aim of stabilizing global temperatures by reducing greenhouse gas emissions (GHGE) and increasing the use of renewable energies.[55] (The US was not a member as of 2017.) The Paris Agreement includes a tracking system along with setting and attaining more ambitious goals every 5 years.[55]

How This Affects the Study of Food Science

- The types of foods available in the future may be limited.
- Climate change may change the nutrient composition of foods and impede the ability to grow foods.
- Optimizing partnerships and research may help minimize the effects of climate change.

Effects of Diet on Climate Change

A landmark report of the UN's Food and Agriculture Organization found that the livestock industry emits large amounts of greenhouse gases (e.g., carbon dioxide, methane, and nitrous oxide) that contribute to climate change.[56] Additionally, this report found that the global impact of the livestock industry included deforestation; water pollution due to animal waste, antibiotics, and hormones, tannery chemicals, and fertilizers/pesticides used on feed crops; eroded pasture; and the loss of biodiversity.[56] While some scientists have expressed concern about the report's calculations and suggest redefining measures and scales,[57] others assert that the annual worldwide greenhouse gas emissions from livestock and their by-products have been vastly underestimated.[58] In the United States, methane emissions from livestock have been found to be 70% greater than emissions from oil and natural gas.[59] Methane has a global warming potential 37% times greater than carbon dioxide.[56] Importantly, approaches to public health nutrition should place climate change and environmental concerns at the center of teaching, learning, advocacy, and practice.[60–62]

Vegetarianism and Completely Plant-Based Diets

An increasing array of evidence-based data indicates that a vegetarian diet and a completely plant-based (vegan diet) are important strategies to combat global warming/climate change.[63–67] For example, researchers in Scotland concluded that a healthy vegetarian diet consisting of locally grown organic foods could reduce Scotland's **ecological footprint** by nearly 40%.[68] More recently, a life-cycle analysis demonstrated that a vegan diet, followed by the vegetarian diet, was associated with the lowest GHGE per serving, per kilocalorie (kcal), and per gram of protein, when this potential was assessed across pescetarian, Mediterranean, and omnivorous dietary patterns.[69] In the United Kingdom, a 2000-kcal diet containing more than 3.5 ounces of meat per day was associated with approximately 2.5 times the GHGE linked to a 2000-kcal vegan diet.[70]

If we do not reduce the world's ruminant meat and dairy consumption, we may not achieve climate stabilization goals.[71] By moving away from meat consumption, we can mitigate the need for agricultural expansion as well.[72] Lastly, transitioning from animal-based diets to a vegetarian or completely plant-based diet could mitigate the dead zone (large algae blooms that suck up oxygen and limit marine life) in the Gulf of Mexico.[73]

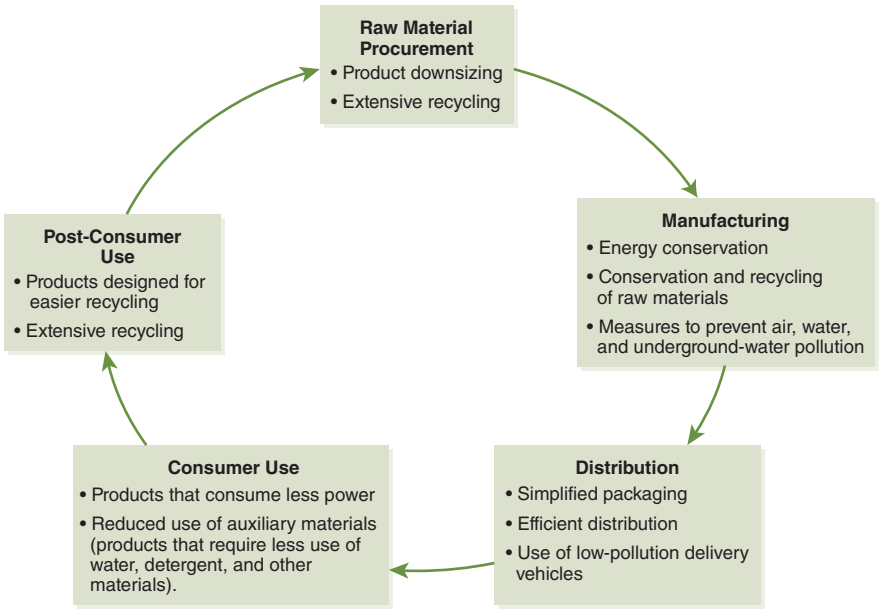

FIGURE 1.10 With the life-cycle assessment method, all the environmental impacts associated with every stage of a product's life cycle, from beginning to end, are analyzed. The results can help consumers make informed decisions about which foods and products they choose to purchase.

Modified from Environmental Protection Agency National Risk Management Research Laboratory's Life Cycle Assessment.

Eating Locally

Some sources advocate eating locally or regionally sourced foods to help combat climate change. While there is nothing more local than growing food in your own backyard, the data are mixed regarding carbon emissions and "food miles" (the distance the food has traveled from its source to you). Some studies have found decreased greenhouse gas emissions with local foods, whereas others have not. For instance, one study used a life-cycle assessment method (**Figure 1.10**) to compare four typically consumed food items sourced both regionally and globally from the state of Washington; the researchers found that locally produced food items contributed to fewer greenhouse gas emissions than imported products.[75] While the need for and importance of locally integrated food systems should not be overlooked,[76] another study found that the type of protein consumed (animal versus plant) plays a bigger role in reducing greenhouse gas emissions than "food miles," with plant foods offering impressive reductions in greenhouse gas emissions.[77] See Figure 1.10.

FIGURE 1.11 Buying food at the farmer's market benefits the environment in a number of ways. First, foods at the farmer's market are usually not enclosed in wasteful packaging. Second, the foods are not transported across the country by trucks that give off greenhouse gases.

How This Affects the Study of Food Science

- Plant-based diets can minimize resource consumption.
- The resource utilization associated with dietary fats should be considered.
- Locally and/or regionally sourced foods can reduce greenhouse gas emissions (**Figure 1.11**).

Effects of Food Waste on Climate Change

It has been reported that food waste in the United States has been underestimated and has progressively increased in recent years.[78] Americans wasted nearly 40% of their food in 2003, and the total is up to 50% in 2017, representing $160 billion in wasted produce alone.[78,79]

The energy content of wasted food is important from an environmental perspective—especially considering the water and energy requirements of food production and the emissions associated with food waste.[80,81] Food scraps represent the second largest percentage of municipal solid waste, after paper and paperboard products.[80] The U.S. Environmental Protection Agency (EPA) created a Food Waste Management Cost Calculator that estimates the costs of alternatives to food waste disposal.[82] As the EPA points out, food waste diversion (keeping organic food waste out of landfills by composting or upcycling) lowers greenhouse gas emissions, enriches soils and mitigates soil erosion, and improves land use.[82] In contrast, when wasted food enters landfills, its decomposition releases methane.[79]

The EPA has an active "Food Recovery Challenge" program.[83] With the goals of reducing ecological impact, increasing food security, and decreasing costs, participants in this program diverted 606,000 tons of food from incinerators and landfills in 2014.[83] Another 218,000 tons of food was composted, while 89,000 tons of food was donated to people in need.[83]

How This Affects the Study of Food Science

- Composting food waste can reduce costs associated with food production and can improve soils.
- Preventing food waste has far-reaching benefits.
- Reducing food waste can save enormous amounts of energy.

Resource Utilization

The resources associated with using animals for food warrant scrutiny. Three-fourths of the soy grown in the world is used for animal feed, and this production is associated with the destruction of native habitats and forests.[84] Most of the soy grown in the United States is genetically modified, with the United States being a major producer and exporter of soy.[84,85]

With nearly 1 billion people undernourished globally,[86] the urgent and imperative need for the increased availability of nutritious food and clean water for the most vulnerable populations is well documented.[86] The highest prevalence of undernourishment is found in sub-Saharan Africa, followed by Southeast Asia and the Caribbean.[86] Redirecting grains fed to livestock and used for biofuels could increase the global calorie supply to meet the basic needs of 4 billion people.[87]

Water Conservation and Drought

Food production should consider the water footprint associated with how and where food is grown—whether it be animal or plant foods. More than 4 billion people globally experience moderate to severe water scarcity at least 1 month per year, while approximately 2 to 3 billion people experience severe water scarcity 4 to 6 months of the year.[88] Drought impacts populations around the globe, with one-third of India facing massive water shortages.[89] In recent times, Cambodia, Laos, and Thailand have suffered from drought and extreme heat, and Malawi continues to struggle with increased food insecurity due to drought-related crop failure.[89] Numerous regions of North America are also experiencing abnormally dry conditions, while parts of the west are experiencing severe drought.[90] As shown in **Figure 1.12**, parts of California are experiencing extreme and exceptional drought.

Generally, production of animal foods utilizes more water than plant-based foods.[91] In an analysis of the water footprint of soy milk and a soy burger in comparison to cow's milk and a beef burger, the water footprint of a soy burger was found to be 7% of that of the beef burger, while the water footprint of soy milk was 28% of that of cow's milk.[92] When soy beans are grown organically,

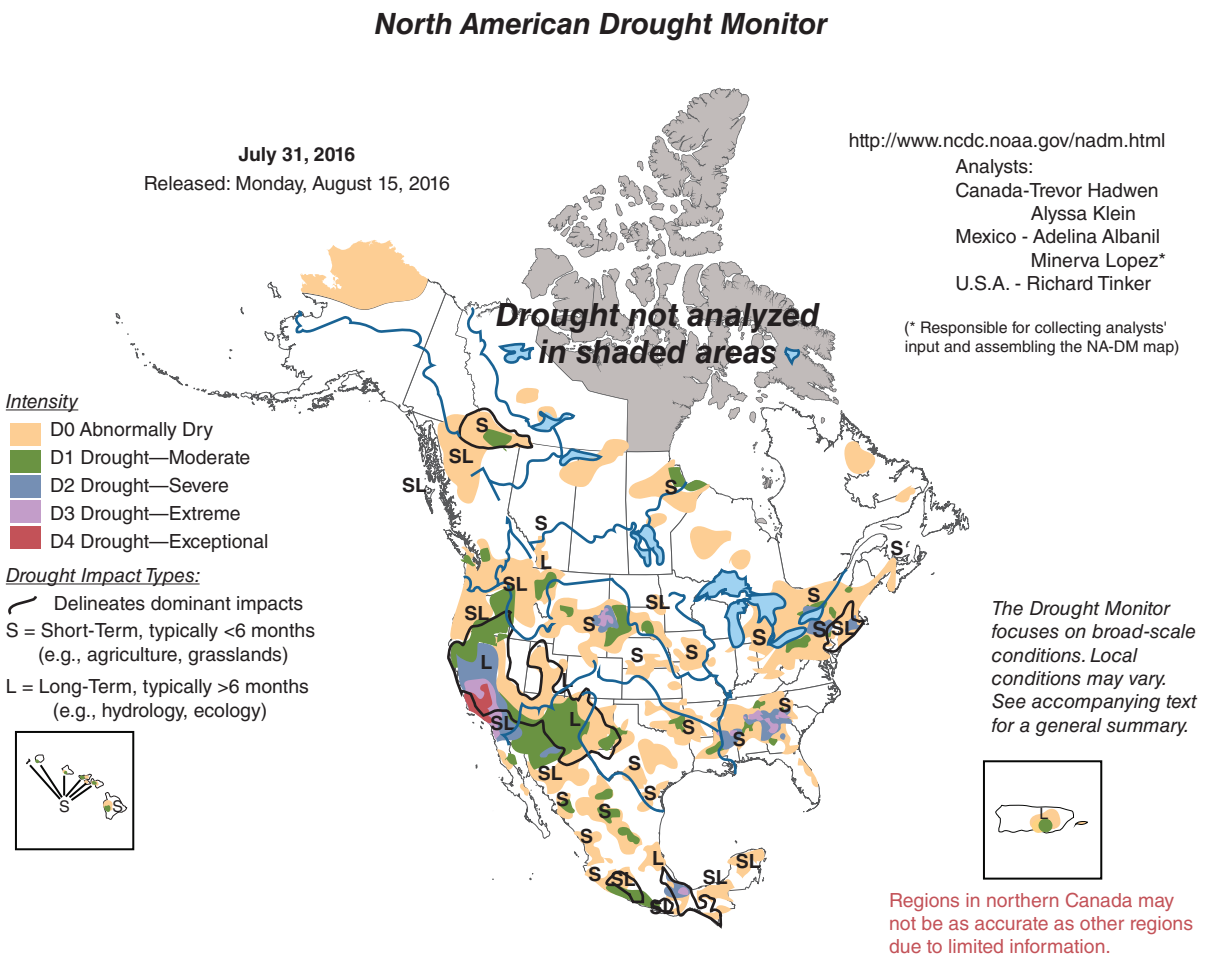

FIGURE 1.12 Map of North American drought representing Canada, The United States, and Mexico. This map of North America depicts numerous areas that are experiencing abnormally dry conditions. Several regions of the United States are experiencing severe drought, with California and northwest Mexico facing extreme and exceptional drought.

Reproduced from NOAA.

they have a lower water footprint due to less soil evaporation.[92] It is also important to recognize that cows are physically stressed during times of extreme heat, which then leads to decreased milk production and death of the animals.[93]

Opposing Impacts of Two Plant Foods: Palm Oil Versus Lentils

While plant foods generally minimize resource consumption, leading to environmental conservation, the opposite is true for conventionally grown palm oil. This inexpensive food oil is readily found in numerous packaged foods and household products such as soaps and is also used for biofuels.[94] Palm oil plantations have destroyed the native habitat of Malaysia and Indonesia, and many other forests around the world have experienced the same plight.[95,96]

Conversely, organically grown lentils can positively impact the natural environment. Understanding the natural cycles of their local ecosystem, the Montana-based USDA Certified Organic farmers of Timeless Foods do not use irrigation for their lentils, leading to resource conservation.[97] As natural nitrogen fixers, lentils can positively impact interspersed crops.[98,99] Thus, growing lentils in this manner enhances the natural environment.

Due to the outstanding nutritional profile of these plant-proteins and their ability to reduce environmental impact, the year 2016 was designated

as "The International Year of Pulses."[100] Pulses include foods such as dried beans, lentils, and chickpeas. Several key messages were highlighted during the 2016 campaign:[101]

- Pulses promote biodiversity.
- Pulses foster sustainable agriculture, climate change mitigation, and adaptation.
- Pulses are highly nutritious.
- Pulses are economically accessible and contribute to food security at all levels.
- Pulses have important health benefits.

As part of the "International Year of Pulses" campaign, marketing materials, social media tips, recipes, and ideas for educational outreach and implementation were made readily available for use, free of charge.[100,101] An example of the promotional graphics associated with this initiative is the "Nutritious Seeds for a Sustainable Future" graphic in **Figure 1.13**.

FIGURE 1.13 Food and Agriculture Organization graphics for "The International Year of Pulses." Graphic depicting slogan, "Nutritious Seeds for a Sustainable Future."
Courtesy of Food and Agriculture Organization, World Health Organization.

Agrichemicals

The use of agrichemicals in agriculture poses many concerns. Even at levels considered environmentally safe, the use of pesticides in three countries was associated with a 40% loss of invertebrate biodiversity.[102] As noted in the planetary boundaries framework, the overuse of agrichemicals such as phosphorus and nitrogen is a grave environmental concern.[27] Furthermore, nitrogen inputs directly contribute to climate change.[103]

In the United States, production of genetically engineered crops increased pesticide use by 404 million pounds over the 1996–2011 period.[104] The use of herbicide-resistant crops introduced an additional 527 million pounds of herbicides into the environment over the same span compared to non-herbicide resistant crops, with the chemicals involved primarily consisting of glyphosate.[104] **Figure 1.14** notes the substantial increases in production of genetically engineered crops in the United States over the last 20 years.

The increased use of glyphosate-dependent crops has contributed to the development of glyphosate-resistant weeds, which have in turn decreased yields and increased costs to farmers.[104,105] After reviewing 1000 studies, the International Agency for Research on Cancer classified glyphosate as "probably carcinogenic to humans."[106,107] However, as a 2016 report from the National Academy of Sciences noted, "There is significant disagreement among expert committees on the potential harm that could be caused by the use of glyphosate on GE crops and in other applications."[108]

Case in Point: Conventional or Organic Bananas?

By examining a seemingly healthful food choice such as a banana, we can contemplate the framework of the *precautionary principle*. While there are slight variations to the definition of the precautionary principle, a simplified rendition goes this way: "When an activity raises threats of harm to human health or the environment, precautionary measures should be taken even if some cause and effect relationships are not fully established scientifically."[109]

The United States is the largest single-country importer of fresh bananas in the world.[110] While conventionally grown bananas dominate the market, organic banana sales have increased 30% from 2000 to 2009.[111] While considered nutritious, bananas are inexpensive to the American consumer and come naturally packaged in their own compostable containers. However, conventionally grown bananas are an agrichemical-intensive crop with notable ramifications to planetary health.[112]

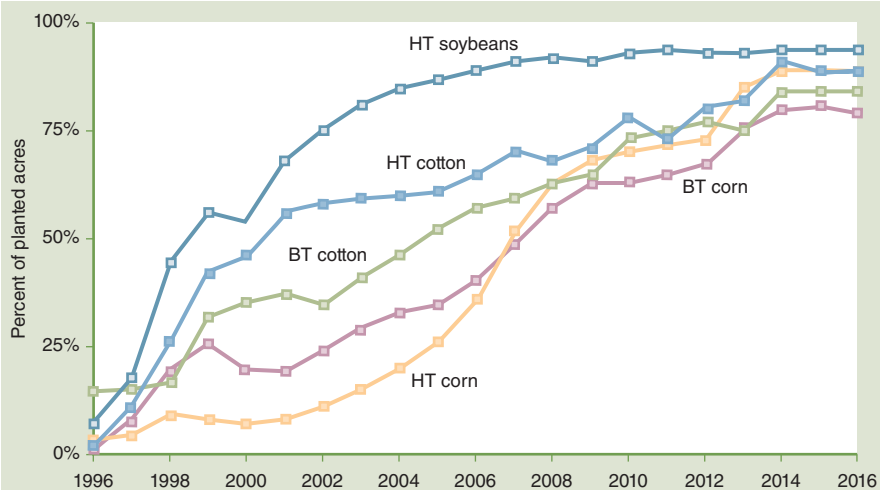

FIGURE 1.14 Genetically engineered crops in the United States.

Reproduced from USDA, Economic Resesarch Service using data from Fernandez-Cornejo and McBride (2002) for the years 1996–1999 and USDA, National Agriculture Statistics Service, June Agricultural Survey for the years 2000–2016.

Researchers studied the effects of the weekly aerial application of the fungicide mancozeb used at large banana plantations in Costa Rica on pregnant women residing in the vicinity.[113] Study participants living within 5 kilometers of a banana plantation had urine concentrations of the mancozeb metabolite five times higher than the general population, with 72% experiencing a rate of exposure higher than the guidelines established by the U.S. EPA's Integrated Risk Information System.[113] Mancozeb is linked to an array of medical disorders, raising concerns about exposure to aerial fungicide spraying.[113,114] Another study in the United States also demonstrated negative consequences for pregnancy when women reside in the vicinity where agrichemicals are sprayed.[115]

Other researchers have studied the impact of pesticides used in Costa Rican banana plantations on the spectacled caiman (*Caiman crodocilus*), a species that lives in nearby waterways (within a national park and a national wildlife refuge, in the study).[116] With seven agrichemicals found in their bloodstream, caimans experienced a diminished body condition, although a decrease in their prey populations in the vicinity may have contributed to this condition as well.[116] The spectacled caiman is considered a *keystone species*.[117] Keystone species play a critical and unique role in the balance of ecosystem functions, such that their disturbance or absence may end those services altogether and cause dysfunction to the ecosystem as a whole.[118] These studies draw attention to the unseen and unintended consequences of our food choices.

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Plastic Debris

Plastic debris has degraded both oceans and other waterways, with more than 5.25 trillion pieces of plastics estimated to be found in the oceans.[119] The United States is among the many countries in the world noted for their plastics mismanagement.[120] Plastic debris can harm wildlife, causing death, dismemberment, and other disorders for a vast array of marine life. For example, an estimated 1 million seabirds choke or become entangled in plastic each year.[121] Disposable food-serving containers such as cups, plates, containers, bottles, and tableware contribute to this problem. Polystyrene, often used as food-serving containers, was observed most often of the debris accumulated in the oceans.[119] The top 10 items collected in Ocean Conservancy's coastal cleanups

included food and beverage serving implements.[122] Hence, responsible plastics management and eliminating the use of disposable food-serving implements can benefit planetary health.

Nutrition Transitions

Nutrition transition A major shift in the types of foods consumed by populations and the resultant effects upon body composition.

It is important to understand how food science is related to nutrition transitions. The term **nutrition transition** describes a major shift in the types of foods consumed by populations and its effect on general health and body composition.[123] Nutrition transitions are studied in relation to the following issues:[123,124]

- Major shifts in population growth and age structure
- Spatial distribution of populations
- Role of the food industry in determining diet structure
- Changes in women's roles
- Public concern for diet and disease prevention
- Complex interactions among epidemiological, socioeconomic, and demographic factors

FIGURE 1.15 The increase in the number of fast-food outlets across the globe has made fast, cheap, and calorie-dense but nutrient-poor foods available to most of the world's population. It also has resulted in increasing obesity-related healthcare costs.

Globally, a nutrition transition to foods that are energy dense and high in fats, cholesterol, and sugars has been documented (**Figure 1.15**).[124] When researchers analyzed survey data from groups ranging from 2 to 18.9 years of age in the United States, the Philippines, China, and Russia, they found that the percentage of calories consumed away from home increased across age groups in the United States from 13.3% of total caloric intake in 1977 to 25.6% of total caloric intake in 1996.[125] Intake of soft drinks, fruit drinks, fast foods, and salty snacks doubled from 10.5% to 21.2% of total calorie intake in the United States from 1977 to 1996, while soft drink consumption as snacks doubled in Philippine youth from 1994 to 2002.[125] In all countries, a higher percentage of urban versus rural residents reported snacking, while the percentage of calories coming from snacks was higher among urban youth.[125] These figures are comparable today.

In another study, when researchers analyzed data from 36 developing countries, they discovered that there are now more women with a body mass index (BMI) greater than 25 (denoting overweight) than women with a BMI less than 18.5 (denoting underweight) in those countries—with the only exception being India.[126] These statistics are troubling because of the general lack of healthcare infrastructure and resources in developing countries for the treatment of diet-related chronic diseases.

Effects of Globalization

Globalization itself has been cited in the creation of lifestyle imbalances that are linked to numerous diet and physical activity-related consequences:[127]

- Worldwide shifts in technology that limit energy expenditure
- Modern food processing
- Communication and distribution techniques that espouse "the Western diet"
- Global expansion of the mass media
- Disappearance of fresh food markets in the developing world

One study found that globalization afforded high-income groups the ability to use the international marketplace for monetary gain, while low-income groups received lower-quality, obesity-promoting foods.[128] Globalization has also been implicated in high food prices and in reducing access of vulnerable populations to nutritious foods.[129]

Removing trade barriers has been shown to increase the amount of food entering a country, affect the types of foods being imported, and decrease the costs of importing food, which increases competition for local food producers.[130] For example, the increased availability of animal products for import has increased animal product consumption in developing countries, while producers in the countries that export the food often receive a subsidy for production.[130] Distorted pricing mechanisms and intense promotion have also increased animal product consumption in developing countries.[131]

Animal-product consumption is predicted to increase in both developed and developing countries, with most of the concomitant growth in livestock production occurring in developing countries.[132,133] Concentrated animal feeding operations (CAFOs), now common in the United States, are likely to be used as a model for meat production in the developing world.[134] This trend is likely to strain ecosystem services, particularly water resources, as discussed in **Special Topic 1.5**. A comprehensive study of industrial farm animal production in the United States concluded, "The present system of producing food animals in the United States is not sustainable and presents an unacceptable level of risk to public health and damage to the environment as well as unnecessary harm to the animals that we raise for food."[134]

Antibiotic Resistance

The assimilation of waste from animals used for food is difficult, given the sheer volume of manure and effluent from the 9 billion animals slaughtered in the United States per year (this includes cattle, chickens, ducks, hogs, sheep/lambs, and turkeys).[135] The associated contaminants are burdensome to biodiversity, humans, and the natural environment.[56,136–138] Antibiotic resistance genes and microorganisms have been found in manure, in the animal products when purchased at grocery stores, and in groundwater and the air.[139–143] The routine use of antibiotics in animal agriculture has clearly contributed to the emergence of antibiotic resistance.[138] Both the CDC and WHO consider antibiotic resistance to represent a major threat to public health, with more than 2 million people being infected with antibiotic-resistant bacteria, and approximately 25,000 deaths from such infections occurring in the United States each year.[144,145] Nearly 80% of the antibiotics produced in the United States are sold to the food animal industry.[138] Removing antibiotics from food animal production has been shown to decrease antibiotic resistance.[146,147]

National Food Trends

Food consumption changes have been noted in the United States as well. In an analysis of National Health and Nutrition Examination Survey (NHANES) data from 1971 to 2002 for more than 39,000 American adults, both the reported amount of all foods and beverages consumed and the total energy intake were found to increase in both men and women during this time.[148] Breakfast consumption declined from 89% in 1971–1975 to 82% in 1999–2002.[148] Researchers also found an increase in the energy density of foods consumed over the past three decades.[148]

In another study, beverages accounted for 12% of total caloric intake in the United States in 1965, but had increased to 21% of this total by 2002.[149] The beverages seeing the greatest increases in consumption included sweetened beverages, alcohol, and unsweetened coffee and tea.[149]

More recent NHANES data have shown that Americans' consumption of fruits, vegetables, legumes, and beans is grossly insufficient across all ages

Special Topic 1.5

Sustainably Feeding the World

Jessica Brie Leonard

As we examine how we can sustainably feed the world, we must first look at the **conventional agriculture** practices currently being employed to feed the world's population. These practices have achieved a high level of pervasiveness because they emphasize high production and low costs, which dovetail with health and food production policy, the demands of the population, and the realities of the ever-evolving marketplace.

Conventional agriculture An industrialized agricultural system whose hallmarks include mechanization, monocultures, the use of chemical fertilizers and pesticides, and an emphasis on productivity and profitability.

Monoculture The cultivation of a single crop and the production of the same crop year-to-year on the same land.

Groundwater Water present below the Earth's surface.

Sustainable agriculture An agricultural system that is founded in the principles of ecology and that is economically viable, socially conscious, and capable of maintaining productivity.

The development of conventional agriculture practices stem from the post–World War II era, when an emphasis was placed on drastically increasing worldwide food production. This push to increase production led to extensive use of pesticides, fertilizers, and water, in addition to the adoption of fast crop rotations and **monoculture**. The positive effects on yield were seen as a measure of success, and the impacts on soil erosion, **groundwater** pollution, water overuse, and chemical-resistant weeds were largely ignored or deemed an acceptable by-product.[1]

The push and pull between the visible and invisible effects of agriculture practices is the cornerstone of the debates over implementation of sustainable agricultural practices. The changes to the environment that cannot be purely tasted, touched, heard, smelled, or seen create a barrier to perception, acknowledgment, and action to change the agricultural system. Media, including the documentary *An Inconvenient Truth*, attempt to fill in the gaps of these perceptions with facts, figures, and projections of where we are headed should policy changes not be implemented. Despite a heightened sense of awareness of the problems, the actions of farmers, consumers, and industry leaders have not been drastically altered. This lack of action is tantamount to an open endorsement of these harmful practices: "How we choose to know, see, and participate within the world can greatly shape how we view the world."[2]

Some elements of food production that mandate a change to **sustainable agriculture** are not directly perceived by the consumer. These aspects include nutrient loss and reduced rates of beneficial microorganisms in the soil as well as increased levels of chemicals in the water table. In contrast, conventional agriculture yields changes that are readily and easily perceived, including weed-free crops, pest-free fields, tall stalks in the fields, high yields, and a uniformity of the product. Meanwhile, the full costs of conventional agriculture are not apparent because they are "externalized to society at-large."[2]

The agricultural policies that allowed for an increase in crop yields have now been found to be environmentally unsound, dangerous in respect to food safety (because food quality is negatively affected), and ultimately the source of food lacking in nutritional quality.[3] The increased pressure set forth by policies that mandate increased crop yields so as to achieve a maximum profit are straining the agricultural system beyond both its physical and practical limits. The fundamental conventional agricultural practices at play here include monoculture, intense tillage, use of petrochemical-based fertilizers, the "pesticide treadmill," environmentally unsound crop irrigation, and the unnatural selection of plant genomes.[3,4]

Whereas farming once meant the growing of crops and raising of livestock, and bringing these goods to market, the current practices favor a monoculture in which specialization has become the norm. Multiple crops and multiple species of livestock no longer coexist on the same farm. Conventional agriculture favors the cultivation of one crop pushed to its maximum yield because it leads to efficiencies in machinery use, weed control, and harvesting, as well as in the purchase of seeds, fertilizer, and pesticides. Sadly, these economies result in an increased need for chemical pesticides as the mono-crops become resistant to the current pesticide preparations.[4]

Farming in a monoculture format also requires excessive tillage of the soil. The aim is to loosen the structure of the soil for better aeration, growth, irrigation, and sowing of the seed. When a singular crop is farmed and the soil is exploited through short crop rotations, the soil loosens

its cover and the quality of the soil is degraded. This degradation takes many forms, including salting, waterlogging, compaction, pesticide contamination, decline in the soil structure, loss of fertility, and erosion by wind and water, to name just a few examples. The degradation of the soil used for farming takes aim at the finite agricultural soil supply, making it difficult to foresee a future for the agricultural industry. Erosion is the most widespread form of this degradation and contributes to a worldwide loss of 25,000 million tons of topsoil washed away annually.[4]

Wasteful water practices, which are currently employed to irrigate crops, are an additional source of concern. In current practices, water is drawn from underground **aquifers** at a rate that exceeds its replenishment by natural rainfall, rivers are drained at the expense of aquaculture, and dams are built that result in unnatural wildlife habitats. The rate at which water is applied to the crops exceeds the crop's ability to take up the water, leaving it to evaporate or drain out of the fields. This evaporation has been seen to alter humidity levels and affect rainfall patterns.[4]

Aquifer An underground layer of rock that when penetrated allows groundwater to be available.

Water also serves as the thoroughfare for the petrochemical-based fertilizers and pesticides that are applied to the crops. The substances are washed away and enter the groundwater, where they become a component of the food chain, are consumed by humans and animals, and find a pathway to prevalence for generations to come. The perpetuation of this chemical pathway is exacerbated by the fact the pesticides that are applied tend to become incapable of killing off the pest population, so that a new preparation must be developed—only to follow the same path toward human consumption. The petrochemical-based fertilizers are also a concern because their production and pricing depend on fluctuations in the nonrenewable oil market.[4]

The proliferation of a monoculture approach to agriculture has resulted in a decline in the genetic diversity of the domesticated plants and animals. "About 75% of the genetic diversity that existed in crop plants in 1900 has been lost."[4] This decline is in large part due to conventional agriculture's emphasis on short-term productivity. The development of a crop variety that results in high productivity and responds to current fertilizers and pesticides supports the short-term production need. The drawback is that the crops become vulnerable to pests as they develop a resistance to the pesticides. The irony of the decline in genetic diversity is that the solution to the problem of pesticide resistance may reside in the natural plant defenses present in the plant population, though a diminishing diversity means a diminishing resource or possible solutions to the problem.[4]

Where Do We Start?

The cyclical nature of our agricultural situation is an ever-present component of the arguments for and against a migration to sustainable agricultural practices. Sustainability centers on "the principle that we meet the needs of the present without compromising the needs of the future."[5] This definition makes a point of addressing the future, though our ability to forecast the future is very limited. The question of whether the remedies to the harm caused by conventional agriculture could create a new category of problems can be addressed only over time. What we can say is that the current practices are causing harm to the environment and affecting the health of the population.

Both simple and fundamental changes are necessary for the agricultural industry to move away from the post–World War II mentality and focus on sustainable practices that will lead the population into the future. Sustainable agriculture has three main objectives: economic profitability, environmental health, and ethical soundness. In practice, these objectives are achieved by maximizing the use of ecological processes, ensuring optimal use of natural resources, and restricting the use of external resources.[1,5]

The least radical strategy is to substitute, rather than overhaul, the current practices. An example of this strategy is replacing toxic chemicals and mineral fertilizers with compounds that are lower-level pollutants, leave fewer residues in the soil, and consume less energy. A substitution strategy that includes the use of biopesticides and the farming of genetically modified plants is seen as a semi-viable short-term strategy. It is not a long-term solution due to the evolution of biocide-resistant pests and concerns over the long-term effects of growing and consuming genetically modified crops.[1]

The agroecological approach is favored over a substitution approach because it aims to apply "ecological concepts and principles to the design, development and management of sustainable agricultural systems."[1] This approach promotes biodiversity and aims to enhance it through cultural practices. The preference for this approach lies in the fact that its goal is to do more than substitute one problem

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for another. That is, the agroecological approach looks to address both the agricultural and cultural components with input from other relevant fields such as ecology and geography.[1]

The agroecological approach acknowledges that sustainable agriculture, population development, and societal development cannot be addressed independently of each other. Rather, they are so closely intertwined that it is difficult to separate them and create steps toward change that will positively impact all of these factors. The best approach for shifting to sustainable agriculture lies in strategies to make better use of our existing resources, including land, water, biodiversity, and technologies. The intensity of the changes adopted is a key component of a sustainable approach to agriculture, with natural, social, and human capital being used in combination with the best practices in available technologies and ecological management. Those practices that minimize or eliminate harm to the environment are those that qualify for implementation.[6]

Agroecosystem An agricultural system that includes crop land, pasture land, livestock land, uncultivated land adjacent to a farm that supports vegetation and wildlife, the atmosphere, soils, groundwater, and drainage. A sustainable agroecosystem focuses on maintaining the natural resource base by relying on a minimum of artificial inputs to manage pests and disease outbreaks in the crops.

In trying to shift toward a more sustainable model of agriculture, technological advances do not need to be ruled out as a part of the solution if they do not cause harm to the environment. Resource-conserving technologies and practices can improve **agroecosystems** through the following strategies:

- Integrated pest management: Use pesticides only when other options are not working, and develop pest, disease, and weed control diversity in the ecosystem.
- Integrated nutrient management: Balance nitrogen fixing with imports of inorganic and organic sources of nutrients, and reduce runoff of nutrients.
- Conservation tillage: Ensure efficient use of available moisture, and reduce tillage so soil can be conserved and erosion avoided.
- Cover crops: Grow crops in the off-season or in conjunction with main crops to maintain healthy soil.
- Agroforestry: Incorporate trees into the agricultural system, and manage forest resources in proximity to agriculture.
- Aquaculture: Incorporate fish, shrimp, and other aquatic life into farm systems, such as irrigated rice fields and fish ponds, resulting in increases in protein production.
- Water harvesting in dryland areas: Improve irrigation and rainfall retention on formerly abandoned and degraded land.
- Livestock reintegration into farming systems: Establish mixed crop and livestock environments to produce improved nutrient cycling on farms.

While technology has a role to play in the agroecological approach, it is not a stand-alone solution. The adoption of technology can sometimes lead to favorable changes, but the role that people play cannot be overlooked. Employing a holistic approach that incorporates an educational component related to the shift toward sustainable agriculture is essential because isolated practices will not yield a perceivable result. A lack of information on how to implement and manage these changes can be a barrier to sustainable agriculture. For this reason, the education of the farming community on sustainable agriculture practices is essential for creating a cultural foundation.[6]

In a survey of farmers conducted in Iowa, it became clear that the shift from conventional agriculture to sustainable agriculture poses a challenge because the planning cycle of the average farmer is 6 months out, at the most. The profit-driven agricultural industry makes it difficult to adopt change and leaves farmers in a position where it is practically impossible for them to choose a long-term approach when faced with 1-year lease arrangements and an emphasis on short-term economic gains.[2]

Within the social culture of farming, there can be additional pressures that are less likely to be validated by the greater society. For example, allowing weeds to be part of the biodiversity of the farmer's crops—a practice that is part of sustainable agriculture—may be perceived negatively by the farmer's peers, creating a stigma. Adoption of sustainable farming practices that are structured incrementally and include a learning component is a key element in building up farmers to experience success in the management of this change. With time and education, there is room for confidence to grow and for farmers to take an active role in the innovation and evolution of new sustainable practices.[2]

Feeding and the Food System

A global strategy expands on the agroecological approach by not only looking at the culture of agriculture, but also looking at society as a whole and recognizing that sustainability is about more than farms. This approach says that "sustainability cannot be solely reached by farming systems, but should also involve the food system, i.e. the relations between farms and food consumption, and the marketing networks."[1]

Inherent in any food system and its agricultural policies is the need to feed the population. These policies cannot be focused solely on increasing the quantity of food produced to feed the population, but must also be focused on the access to, and quality of, the food produced. "A secure food supply satisfies the consumer's needs without jeopardizing the production process in the short or long term. It ensures the sustainability of supplies while considering the safety of methods of production and the nutritional stability of the food produced."[3]

The relationship between food security and sustainability is addressed in WHO's First Action Plan for Food and Nutrition Policy, which includes the following principles:

- The ways in, and means by, which food is produced and distributed respect the natural process of the Earth and are thus sustainable.
- Both the production and consumption of food are grounded in and governed by social values that are just and equitable as well as moral and ethical.
- The ability to acquire food is assured.
- The food itself is nutritionally adequate and personally and culturally acceptable.
- The food is obtained in a manner that upholds human dignity.[3]

On a global scale, the focus of food production and health policies shifted from increased food production and its distribution in the early to mid-twentieth century to correction of nutrient deficiencies in the second half of the twentieth century. Recently, the focus has shifted yet again, with the emphasis being placed on adopting an approach toward food production that considers its ecological impact. This concern can be seen in the international resolutions in Agenda 21, which were endorsed by the 1552 United Nations Conference on Environment and Development, and address the relationship between agricultural production and the impact on the environment. WHO has also begun to focus on concerns over "the loss of biodiversity, desertification and ecological degradation, water and air pollution, the social and psychological effects of depleted environments, and issues of social justice and human rights and food production."[3]

While the current approach to food production may be based in science, its basis is not in environmental science. The transformation of food production from agriculture to **agribusiness** has seen the introduction of practices such as genetic selection of crops and breeds of animals, the spraying of crops and animal feed with nutrients, and the use of biochemicals to increase yields. These developments have garnered financial gains for food producers and, therefore, have been widely adopted and endorsed. This endorsement should not be mistaken as a validation of the practices. The increased abundance of food and reduced food costs has caused an increase in food safety risks and damage to the environment.[1]

Agribusiness A complex system of businesses involving food production, the people involved in food production, and companies that produce the inputs needed to produce the food, such as seeds, chemicals, and lines of credit. This system also includes the output of food products by manufacturers, their processing, packaging, transportation, and marketing.

Methods	Results
Genetic selection of and breeds of animals Spraying of crops and animal feed with nutrients Increased yields through the use of biochemicals, such as pesticides and growth enhancers Use of veterinary medicine to prevent disease outbreaks among confined animals and to promote weight gain and productivity[3]	Reduced labor costs Increased mechanization Development of monoculture patterns Increased field, herd, and flock sizes Reduced biodiversity of crops Increased transport distances Increased food processing and additive use Increased concentration of retailing outlets Increased marketing and advertising of food products[3]

Modified from World Health Organization. *Food security and sustainable development. Food and health in Europe*. January 2003:25-215.

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A Producer–Consumer Disconnect

Given that the deficiencies that set the current food policies in motion are no longer at the forefront of nutritional concerns, these policies need revision to address the current situation. This separation of the needs of society from the policies and practices of the agricultural industry represents a disconnect between the producer and the consumer, and one that creates an artificial demand. Ideally policies geared toward meeting the needs of the population through food production will address the nutrient density and biochemical diversity of the food supply. Deterioration in the nutrient content of food has been a result of decreased biodiversity and increased processing and preservation of foods in which the emphasis is on visual appearance.[3]

This emphasis on product presentation has evolved simultaneously with the food industry's evolution into a player in the global marketplace. Food now moves rapidly around the world, with processing, packaging, and preserving of that food now consuming the highest percentages of the food dollar. Farmers are left with "less than eight cents on the food dollar spent."[4] Farmers are also placed in a difficult position when they choose their variety of crop, and must plant the variety that is being bought, generally by a large transnational corporation.[4]

Different types of foods have different environmental impacts. For example, fresh produce has a much smaller environmental cost than a package of potato chips.

The emergence of agribusiness is a direct result of the commodification of food. As food has been transformed into a commodity in the global economy, this trend has changed the tastes and the behaviors of the consumer. Specifically, producers have created a demand for products with a high potential for profit, such as fast foods, processed snacks, exotic fruits, and out-of-season vegetables. Unfortunately, these foods carry the highest environmental costs (see the accompanying figure), and their purchase supports the least sustainable practices.[4]

Community Action

To rectify this detrimental situation, a closer relationship needs to be established between the consumer and the farmer. Education of consumers on, and refocusing of consumers' diet away from, animal products and foods requiring excessive transport and processing is a good place to start. For the farmers, the road is longer and more complex, but can be centered on creating and conserving healthy soil, conserving water and protecting water quality, managing organic wastes to avoid pollution, selecting plants and animals that are adapted to the local environment, encouraging biodiversity, managing pests with minimal environmental impact, and conserving nonrenewable resources.[4,7]

Pushing to reestablish the local farmer as the consumer's food source is a course of action that communities can take to support sustainable agriculture. Shorter food supply chains lessen the number of links in the food supply, creating a more cohesive food community. It is also up to the consumers and community to require more information on the food they are buying—from its nutritional content to its point of origin. Through this level of free information exchange, consumers can become educated on the practices their purchases are supporting and spend their food dollar more sustainably.[4]

While the issues created by our current conventional agricultural practices are deeply rooted in agribusiness, the adoption of more sustainable practices has the potential to have a positive impact on the environment and our food supply. It is this focus that must be adopted to move the migration to sustainable agricultural practices forward and allow for positive changes in our environment.

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and all genders.[150] Conversely, Americans are overconsuming refined grains and empty-calorie foods (**Figure 1.16**).[150]

How This Affects the Study of Food Science

- Food choices are linked to globalization.
- Cultural traditions related to food are being displaced.
- Changes in the composition of food and the types of foods consumed can affect food preparation, human health, and the natural environment.

FIGURE 1.16 Today's foods are more energy dense than in the past, which can make it easy to consume too many empty calories.

The Burden of Diet-Related Chronic Diseases

Heart disease is now the leading cause of mortality both worldwide and in the United States.[151] Notably, the leading causes of mortality in the United States, such as certain cancers, diabetes, and stroke, are diet related.[151] Two-thirds of Americans are considered overweight or obese; obesity is a risk factor for hypertension, diabetes, metabolic syndrome, and various cancers.[152] Over the past 30 years, childhood obesity in the United States has increased by 30%.[153] By 2050, one in three Americans is projected to have diabetes.[154]

The American Cancer Society notes that a "substantial portion of cancers can be prevented,"[155] while the American Institute for Cancer Research suggests that nearly half of all colorectal cancers could be prevented with a healthful diet, exercise, and maintaining a healthy weight.[156] Obesity, lack of physical activity, and unhealthy dietary patterns such as high consumption of red or processed meats and low intake of whole grains, fiber, fruits, and vegetables are risk factors for various cancers.[155] After reviewing 800 studies, the International Agency for Research on Cancer classified processed meats (meats that have been salted, cured, fermented, or smoked such as ham, sausages, frankfurters, and canned meat) as "carcinogenic" and red meats (beef, pork, lamb, veal, mutton, horse, and goat) as "possibly carcinogenic."[157,158] This committee did not include the assessment of chicken or fish.

Importantly, the 2015 Scientific Report of the Dietary Guidelines Advisory Committee identified that a healthy dietary pattern is higher in plant foods such as vegetables, fruits, whole grains, legumes, and nuts.[150] The committee also found diets higher in plant-based foods had less environmental impact.[150]

Concern for the Natural Environment Among Health Professionals

Health professionals have demonstrated concern for the natural environment. A survey of registered dietitians credentialed in the United States (n = 570) found that 75% are strongly concerned or concerned about climate change.[159] A survey of public health nurses in the United States (n = 126) found that 75% believe that humans are severely abusing the natural environment.[160] The American College of Physicians offers climate change guidelines for physicians, including "reduce the amount of meat protein on menus, buy local and seasonal food, procure organic food when possible, prevent waste in food services, compost food waste, eliminate bottled water."[161] The International Federation of Medical Students' Associations, in partnership with WHO, created a climate and health training manual for medical students.[162] The medical journal *The Lancet*, in collaboration with the Rockefeller Medical Foundation, has drawn attention to planetary health.[25]

Despite these efforts and concern, deficits remain in practice. Only 8% of dietitians report that their workplaces offer funding for diet-related interventions to mitigate climate change.[159] A survey of local health departments (n = 133) found that only 33% have programs to help people shift dietary patterns to organic, local, and plant-based foods.[163] Public health nurses report they feel unable to address climate change within their workplaces.[160]

While the challenges of creating paradigm shifts are duly noted, some health professionals and healthcare organizations are blazing new trails of green by way of actions to improve planetary health. Several are highlighted here:

- *Health Care Without Harm* is an international coalition that has been a force in guiding the healthcare sector to healthier outcomes for planetary health for more than 20 years.[164] Its mission is to transform the healthcare sector so as to minimize its ecological footprint and help create a sustainable, equitable, and healthy world.[164] Health Care Without Harm helps hospitals and healthcare organizations create practices and policies such as removing toxic chemicals from the hospital environment, reducing the amount of meat served in hospitals, promoting clean and renewable sources of energy, reducing antibiotic resistance, shifting hospitals' purchasing practices in ways that promote planetary health, conserving water and avoiding bottled water, and recycling and composting.[164] Its "Healthy Food in Health Care" program has enlisted more than 1000 hospitals in North America.[165] More than 600 health organizations are also members of the "Global Green and Healthy Hospitals" initiative.[166] The nearly 400 hospitals in this network recycled 122 tons of waste in 2014.[166] In addition, these hospitals reduced their energy consumption, saving nearly 74,000 metric tons of carbon dioxide equivalents, and 115 hospitals allocated $35 million for local and sustainable food purchasing.[166] Numerous New England health organizations have also prioritized values-based purchasing by focusing on locally produced organic foods to support the local economy while improving planetary health.[167]
- *The Washington Toxics Coalition* works to eliminate toxic chemicals that accumulate in the environment and in humans. It lists the ban of bisphenol A (BPA) from baby bottles, children's drink cups, and sports bottles in the state of Washington as one of its accomplishments.[168]

- *The Center for Food Safety* works to curb the proliferation of harmful food production technologies and promotes sustainable agriculture.[169]
- *The Hunger and Environmental Nutrition Practice Group* of the Academy of Nutrition and Dietetics envisions optimizing the U.S. population's health by promoting access to nutritious food and clean water for a secure and sustainable food system. Its aspiration is to create a "sustainable and resilient food system that conserves and renews natural resources, advances social justice and animal welfare, builds community wealth, and fulfills the food and nutrition needs of all eaters now and in the future."[170]
- *The Vegetarian Nutrition Dietetic Practice Group* of the Academy of Nutrition and Dietetics is a leading authority in disseminating evidence-based research on all types of vegetarian diets (**Figure 1.17**).[171] Recognizing the merits of plant-based diets in reducing impact on the natural environment, this group recently created a resource for professionals entitled "Plant-Based Diets in Climate Change Mitigation and Resource Conservation."[172]
- *The Tzu Chi Medical Foundation* is an international humanitarian organization that consists of medical clinics, hospitals, and mobile emergency operations facilities. Environmental protection is at the heart of all Tzu Chi operations.[173] The creators of "Ethical Eating Day," Tzu Chi encourages consumers to eat more meatless meals so as to reduce greenhouse gas emissions and for environmental and other ethical concerns.[174] In 2017, Ethical Eating Day fell on January 11.
- *The Humane Society of the United States* has developed the "Food Forward" program. Food-serving institutions can benefit from this free 2-day plant-based culinary training program, which is designed to increase the number of wholesome and delicious plant-based meals served and enjoyed.[175]
- *Green Monday* is a social startup company that aims to combat climate change and global food insecurity with a plant-based dietary approach to create a green, sustainable, and actionable lifestyle among corporations, restaurants, schools, and the general public.[176]

Concern and care for the natural environment are also demonstrated by individuals within health organizations and across disciplines:[177,178]

FIGURE 1.17 Icon is from the Vegetarian Nutrition Dietetic Practice Group and Academy of Nutrition and Dietetics.

Courtesy of Vegetarian Nutrition Dietetic Practice Group, the Academy of Nutrition and Dietetics.

FIGURE 1.18 Equal Exchange from Jessica Jones-Hughes.

Courtesy of Jessica Jones-Hughes, Equal Exchange.

FIGURE 1.19 Making a small change, such as using reusable coffee mugs, is an easy way to reduce the amount of waste generated in an office setting.

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- Some general practice physicians advocate linking patient health promotion recommendations to environmental sustainability. They do this by encouraging patients to eat more plant-based foods and fewer animal products as well as by promoting walking, biking, and use of public transportation as an alternative to driving a car.[179]
- Some individuals promote increased self-reliance for food preparation and food production—such as cooking and growing one's own food.[180,181]
- A large health benefits company in Massachusetts provides a member discount for professionally installed organic raised-bed vegetable gardens and gardening advice to make growing organic vegetables at home easier.[182]

How This Affects the Study of Food Science

- Decreasing bottled water use can reduce negative impacts on the natural environment.
- Chemicals in food packaging can accumulate in humans.
- Numerous organizations place great importance on reducing impacts on the natural environment and improving human health via food, water, and water quality.

Putting Theory into Practice

The following four narratives illustrate how specific organizations and individuals are putting theory into practice.

Working to Change the Global Food Supply Chain

Jessica Jones-Hughes, MS, RD, is the vice president of Oke USA and the Equal Exchange banana manager (**Figure 1.18**). Jones-Hughes and her company are working to change the global food system by offering a democratic and fair process for small organic farmer cooperatives that puts them in control in the supply chain, with their profits being directed back to ensure growth of the cooperative.[183] The health of workers, banana consumers, and the environment is a top concern for these cooperative organic farmers and Equal Exchange.[183] While Equal Exchange has spent 10 years cultivating organic fair trade bananas, it has also created markets for products such as organic shade-grown coffee that benefits survivors of violent sexual assault in the Democratic Republic of Congo.[183] Jones-Hughes is motivated by the fact that people who have a choice in their food behaviors can empower a better food system for all.[184]

How This Affects the Study of Food Science

- Organic farming cooperatives can increase the global supply of wholesome foods.
- Organic farming methods improve planetary health and protect planetary boundaries.
- Organic foods sales continue to increase in the United States.

Minimizing Food-Serving Container Waste

Dr. Lynn Foord, PT, an associate professor at Massachusetts General Hospital's Institute for Health Professions, drinks a cup of coffee every day. Instead of using a coffee cup made of paper and plastic components that is thrown away each day, Foord uses a reusable coffee mug (**Figure 1.19**). She made this change after noticing and reflecting upon the large volume of waste the

disposable cups produce. "It was when my trashcan was not emptied once for a week that I saw the unnecessary volume of trash that I was responsible for, which moved me to reflect on my personal behaviors and propelled me to action," Foord noted.[185] Foord also brings her lunch to work in a reusable lunch tote, complete with reusable tableware, eliminating large quantities of disposable food container waste.

How This Affects the Study of Food Science

- Changing personal behaviors can reduce unnecessary food container waste, which otherwise would impose a burden on the natural environment.
- Contemporary eating patterns have led to increased food container waste.

Creating a Green Kitchen

Barbara Hartman, MS, RD, is the chief dietitian and food service director at the Veterans Affairs Medical Center in Martinsburg, West Virginia. Hartman's food service team instituted a "Comprehensive Green Kitchen," whose practices include procuring locally grown produce and conserving energy and water.[186] They continuously reduce waste by taking the top tier of the EPA's Food Recovery Hierarchy "source reduction" seriously (**Figure 1.20**). Hartman puts it another way: "Don't waste in the first place!" Using both a manual and an electronic tracking system, Hartman's team has improved menu planning and forecasting, with the electronic tracking system paying for itself within 6 months.[186] With their "waste watchers" program, they determined that they were wasting 19,000 pounds of food per quarter, but decreased that amount to 3000 pounds. This equated

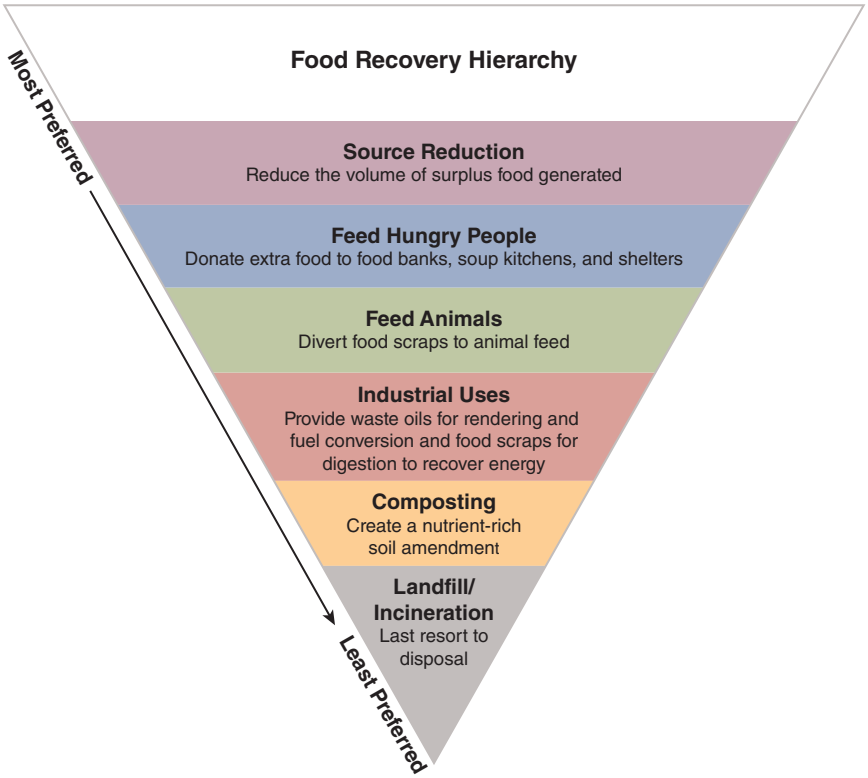


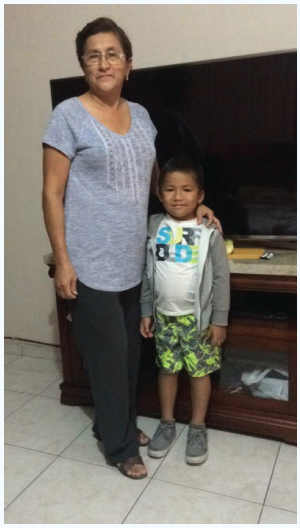
FIGURE 1.20 EPA food recovery hierarchy.

Reproduced from the Environmental Protection Agency. Retrieved from: https://www.epa.gov/sustainable-management-food Accessed October 8, 2016.

Special Topic 1.6

Mariana Cobos, Organic Banana Farmer

Mariana Cobos has been producing bananas since 2004. In the beginning, Cobos was trying to earn a living by producing bananas. However, the situation in Ecuador is very difficult for small-scale banana farmers, as they face many challenges in terms of pricing and rules imposed by multinational companies. It was hard for Cobos to keep producing with minimal rewards. At that point, she decided to do something different so as to keep producing bananas in an ethical and profitable way. In 2006, Cobos joined the farmer cooperative AsoGuabo. After meeting many requirements to get her farm certified as Organic and Global GAP, Cobos was able to become a member of AsoGuabo. Today, she is pleased to produce organic fair trade bananas on 11.5 hectares of land. Now age 63, she is an AsoGuabo board member and serves as an inspiration for younger women such as Karla Inine Lozada Carreno, who farms in Peru. Both are Equal Exchange cooperative farmers.



Courtesy of Equal Exchange.

Mariana Cobos of Ecuador
Courtesy of Equal Exchange.

Karla Inine Lozada Carreno of Peru.
Courtesy of Equal Exchange.

to savings of $40,000 per year. Importantly, team members are working toward the long-term goal of achieving a zero-waste kitchen.

When an employee approached Hartman and asked, "Can we do something else with the leftover food besides throw it in the trash at night?", the Food Donation program was born. By capitalizing on the team's tenacity and logistical acumen, 250 pounds of food is donated per week, equating to 37,000 pounds per year. This food becomes the evening meal for transitional veterans who are being served at two local nonprofit locations.[186]

Hartman and colleagues also created an on-site composting facility. Using items such as their produce peels and food scraps, they create a nutrient-rich soil that is used on their campus, including in the Veterans Healing Gardens.[186]

Hartman takes pride in letting her staff lead the way. When their department was recognized by the president and vice president of the United States, she ensured all employees received a copy of the Presidential "Green Gov" Award. Hartman and company used a quote from Walt Disney, "It's kind of fun to do the impossible," for inspiration when they began, but with their success they are now looking for a new quote to drive the program even further.[186]

How This Affects the Study of Food Science

- Composting offers valuable nutrients for soil health.
- Preventing food waste is a commitment that starts with source reduction and entails creativity and tenacity.

Closing the Loop

The Tzu Chi hospitals promote and enact environmental protection in all ways possible. They not only strive to maximize resource conservation and energy efficiency in their facilities, but also serve plant-based meals.[187] The resource utilization and waste associated with medical care is enormous, yet the Tzu Chi hospitals have successfully developed and implemented innovative solutions to this ongoing problem.

For example, dialysis tubing is typically discarded after being used for one patient. At the Tzu Chi clinics, the dialysis lines are sorted immediately after use by the nursing staff for recycling.[187] The tubing is autoclaved/sterilized to remove the hazards associated with biowaste.[187] This plastic is then upcycled and used to make items such as blankets used in emergency operations and clothing such as shirts, pants, and suits.[187] Additionally, upon starting employment at a Tzu Chi hospital, each employee receives a personal set of reusable tableware that saves scores of disposable plastics from the landfill or otherwise contaminating the natural environment.[187]

From novel solutions such as exclusively serving plant-based meals to innovative waste reduction and upcycling solutions, the Tzu Chi Medical Foundation demonstrates an exemplary path of how healthcare facilities can operate to improve planetary health and to protect our planetary boundaries.

How This Affects the Study of Food Science

- There are numerous inventive ways to decrease waste and to conserve resources.
- Offering plant-based meals in a hospital setting not only reduces impacts on the natural environment and improves public health, but also demonstrates a commitment to protecting our planetary boundaries.

Chapter Review

These examples of nutrition ecology in practice demonstrate an awareness of the living systems of the natural environment by way of simple actions that reduce negative impacts on the natural environment. They are thoughtful responses to the pressing issues that connect food to the living systems of the natural environment, encountered daily. Scientific data support further efforts to understand and reduce our impacts on the living systems of the natural environment by making food choices that can create important improvements—especially if changes are incorporated over large numbers of people. Furthermore, the content presented in this chapter demonstrates the unequivocal interconnectedness of humans, food, and the natural environment. While the phrase "Thinking of food, energy, and diet as one"[188] is most timely, we can extend this thinking to consider food, the living systems of the natural environment, and humankind as one. Restructuring our relationship with the natural environment in a way that also considers how food and food systems impact planetary health and our planetary boundaries is one of our greatest challenges today.

Case Study

Digging Deeper into GMO Foods: Are There Concerns?

Courtesy of Christine McCullum-Gómez, PhD, RDN, Food and Nutrition Consultant, Houston, Texas

Genetically Engineered/GMO Food Crops

Genetic engineering is one type of genetic modification that involves the intentional introduction of a targeted change in a plant, animal, or microbial sequence to achieve a specific result. Genetically engineered (GE) foods, also known as GMO (genetically modified organism) foods, have been in the U.S. food supply for approximately 20 years. Many plants that are genetically engineered are herbicide tolerant and/or insect resistant.[1] Examples of other GE food crops include herbicide-tolerant sugar beets, herbicide-tolerant alfalfa, drought-tolerant maize, virus-resistant papaya and squash, blight-resistant potatoes, and nonbrowning "Arctic" apples.[2–6]

Countries with the Highest Adoption Rates of GE Crops

The United States continues to lead the world, with 70.9 million hectares of GE crops planted, with a 94% adoption rate for GE soybeans, a 92% adoption rate for GE maize/corn, and a 94% adoption rate for GE cotton. Brazil follows in second place with 44.2 million hectares of GE crops planted (soybeans, maize/corn, and cotton); Argentina has 24.5 million hectares planted (soybeans, maize/corn, and cotton); India has 11.6 million hectares planted (cotton); and Canada has 11.0 million hectares planted (canola, maize, soybeans, and sugar beets).[2]

A Lack of Consensus on the Safety of GE Crops/GMOs

A statement released in 2015, and signed by 300 scientists, physicians, and scholars, asserts that there is no scientific consensus on the safety of GMOs.[7,8] Many concerns have been raised about increased herbicide use, potential health impacts, and the spread of herbicide-resistant weeds. International agreements such as the Cartagena Protocol on Biosafety and the United Nation's Codex Alimentarius share a precautionary approach to GE crops/GMOs by recognizing that genetic engineering differs from conventional breeding, and by stating that safety assessments should be required before GMOs are used in foods or released into the environment.[8] A comprehensive review of peer-reviewed animal feeding studies of GMOs found approximately an equal number of research groups raising concerns about GMO foods versus suggesting GMOs were as safe and nutritious as conventional foods.[9] This same review found that most studies concluding that GMOs are the same as conventional foods were performed by biotechnology companies or their associates.[8,9]

Increased Use of Glyphosate-Based Herbicides with Adoption of GE Herbicide-Tolerant Crops

In 1996, "Roundup Ready" (RR) GE herbicide-tolerant soybean, maize, and cotton varieties were approved for planting in the United States. These varieties dramatically extended the time period during which glyphosate-based herbicides could be applied.[10] Alfalfa and sugar beets engineered to tolerate glyphosate were first approved and commercially marketed in 2005 and 2008, respectively. However, federal lawsuits—citing violations of the National Environmental Policy Act—delayed full commercial sales until 2011 for RR GE alfalfa and 2012 for RR GE sugar beets.[10]

Globally, glyphosate use has risen almost 15-fold since GE herbicide-tolerant crops were introduced in 1996.[10] For more than a decade, glyphosate-based herbicides have been, by far, the most heavily applied pesticides in the United States.[11] They are also the world's most heavily applied herbicides.[11] Growing reliance on the broad-spectrum herbicide glyphosate has triggered spread of tolerant and resistant weeds both in the United States and globally.[10,12–16] To fight weeds that are less sensitive to glyphosate, farmers typically increase glyphosate application rates and spray more often.[17–19] Next-generation GE herbicide-tolerant crops are, or will soon be, on the market that are genetically engineered to withstand the application of additional herbicides, including herbicides that pose greater ecological damage, crop damage, and human health risks (e.g., 2,4-D and dicamba).[13]

Residues of glyphosate and its principal metabolite, aminomethylphosphonic acid (AMPA), are present in nearly all soybeans harvested from fields planted with GE herbicide-tolerant soybeans.[11,20–21] Glyphosate and AMPA have been detected in the air,[22] soil,[23] and water.[24,25] Regulatory bodies around the world assert that levels of glyphosate in the air, water, and food result in typical human exposure estimates that remain well below the "levels of concern" or "Acceptable Daily Intakes."[10] That said, a growing body of literature suggests possible adverse environmental, ecological, and human health consequences from glyphosate and AMPA, both alone[11] and in combination

with ingestion of GE proteins.[26] Environmental studies[10] describe possible glyphosate impacts on soil microbial communities and earthworms,[27–29] monarch butterflies,[30] crustaceans,[31] and honeybees.[32]

Collectively, studies from laboratory animals, human populations, and domesticated animals suggest that current levels of exposures to glyphosate-based herbicides can induce adverse health outcomes.[11] Studies assessing possible risks of glyphosate-based herbicides to vertebrates and humans include evidence of increased glyphosate residue levels in soybeans,[21,33] increased cancer risk,[34] and risk of other potential adverse impacts on development, the liver or kidney, or metabolic processes.[10,11]

Multiple studies on glyphosate-based herbicides have reported effects indicative of endocrine disruption following exposure to these chemicals.[35–38] The increased incidence of severe birth defects in Argentina and Paraguay in areas where GE/GMO herbicide-tolerant crops are widely grown may be linked to ability of glyphosate-based herbicides to increase retinoic acid's activity during fetal development.[37] Glyphosate-contaminated soybeans used in the pork industry have been associated with elevated rates of gastrointestinal-health problems and birth defects in young pigs.[39] Related impacts have been observed in poultry.[40] Increases in the frequency of serious, chronic kidney diseases have been observed in male workers in some regions where there is a combination of heavy glyphosate-based herbicide use and hard water.[41,42]

Finally, a recent report demonstrates that concentrations of commercially available glyphosate-based herbicides alter the susceptibility of bacteria to six classes of antibiotics (e.g., by either raising or lowering the minimum concentration needed to inhibit growth).[43] In addition, glyphosate-based herbicides can induce multiple antibiotic-resistance phenotypes in potential human pathogens (*Escherichia coli* and *Salmonella enterica* serovar *Typhimurium*). Such phenotypes could both undermine antibiotic therapy and significantly increase the possibility of mutations conferring more permanent resistance traits. Since glyphosate-based herbicides and antibiotics are widely used on farms, farm animals may be exposed to both—with a concomitant decrease in antibiotic effectiveness and increase in the diversity of newly resistant bacterial phenotypes that could impact the human population.[11,43]

Next Steps in Addressing Research Gaps

The upward trend in glyphosate use will likely contribute to incremental increases in environmental and human exposures to glyphosate and its metabolite AMPA.[10] Regulators do not require testing of chemical mixtures, nor do they conduct any additional risk assessments designed to quantify possible additive or synergistic impacts of multiple herbicides applied.[11] The process of establishing testing protocols for endocrine-mediated impacts has been under way in the United States since 1997, in response to a mandate in the 1996 Food Quality Protection Act to consider such effects in assuring a "reasonable certainty of no harm" for pregnant women, infants, and children. Seventeen years later, the EPA remains years away from codifying a new battery of tests capable of identifying risk of low-dose, endocrine disruption–driven effects.[11]

Another challenge to the accurate assessment of these herbicide formulations is that the full list of chemicals in glyphosate-based herbicides is protected as "confidential business information."[11] Hence, many of their effects would likely not be detected in experiments adhering to traditional toxicology test guidelines promulgated by pesticide-regulatory authorities.[11] To address these gaps in knowledge, a thorough, modern assessment of glyphosate-based herbicide toxicity needs to encompass potential endocrine disruption, impacts on the gut microbiome, carcinogenicity, and multigenerational effects looking at reproductive capability and frequency of birth defects.[11]

GE Salmon

In November 2015, the U.S. Food and Drug Administration (FDA) approved the first GE animal for commercial food production, an Atlantic salmon engineered to grow quickly.[2] The GE salmon was created by Aqua Bounty Technologies with DNA from three fish: Atlantic salmon, Pacific king salmon, and Arctic ocean eelpout.[44] In approving the GE salmon, the FDA did not require labeling of GE fish, which led Congress to call for labeling in the 2016 omnibus spending bill.[44] The FDA's approval also ignored comments from nearly 1 million people in opposition, as the agency failed to analyze risks to wild salmon and the environment, the impact on fishing communities, and the risk that the GE salmon could escape and threaten wild salmon stocks.[44]

Perhaps not surprisingly, a broad coalition of environmental, consumer, and fishing organizations sued the FDA for approving this salmon.[44] The lawsuit challenges the FDA's claim that it has the authority to approve and regulate GE animals as "animal drugs" under the 1938 Federal Food, Drug, and Cosmetic Act.[44] The lawsuit also highlights the FDA's failure to protect and consult wildlife agencies in its review process, as required by federal law. When GE salmon escape or are accidently released into the environment, the new species could threaten wild populations by mating with endangered salmon species, outcompeting them for scarce resources and habitat, or

(*continues*)

introducing new diseases.[44] Studies have shown that there is a high risk of GE organisms escaping into the natural environment, and the GE salmon can crossbreed with native fish if they do so.[44]

In a 2103 *New York Times* poll, three-fourths of Americans said they would not eat a GE fish.[45] In 2010, a national survey found that 78% of U.S. adults believed the FDA should not approve GE salmon for human consumption, compared to just 16% who wanted to see it approved.[46] Regardless of the FDA decision, more than 60 major retailers have announced they have no plans to sell the GE salmon, including Aldi, Giant Eagle, H-E-B, Kroger, Safeway, Target, Trader Joe's, and Whole Foods.[47,48]

GMO Labeling and the Need for Enhanced Regulation of GE/GMO Foods

Despite the fact that more than 60 countries worldwide require GMOs to be labeled, the U.S. government does not.[4,49] On July 29, 2016, President Barack Obama signed Public Law 114-216—legislation passed by Congress that would preempt state labeling laws but create a national mandatory GMO labeling standard.[49]

A recent expert panel convened by the National Academy of Sciences to assess genetic engineering of crops confirmed that without mandatory labeling, consumers would not know whether a product contains GE ingredients and, therefore, could not make their own personal risk–benefit decisions.[50,51] This same expert panel concluded that GMO crops, to date, have not increased yields and should not be exclusively relied upon to meet long-term food security needs. The panel called for modernization of the GMO regulatory system, including new limits on GMO crops and the chemicals used with them.[50,51]

In the absence of mandatory labeling requirements for GMO foods in the United States, food companies are using voluntary labeling options for those consumers who wish to avoid GMO foods.[52] The most reliable labels include the following:

- *USDA Organic Certified.* National and state organic certification rules do not allow GE foods to be labeled as "organic."
- *Non-GMO Project Verified.* This label is obtained through a voluntary certification process operated by a nonprofit organization called the Non-GMO Project.

For more information on product availability and retailers that carry these products, visit www.nongmoproject.org.

Questions

1. Describe at least two ways that the precautionary principle applies to the use of GMO foods.
2. Can a food that is labeled USDA Certified Organic be made with GE technologies?
3. Can we solely rely on increasing the global food supply with GE foods?

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Courtesy of Christine McCullum-Gómez, PhD, RDN, Food and Nutrition Consultant, Houston, TX.

Learning Portfolio

Key Terms

Study Points

1. Restructuring our relationship with the natural environment to enact the principles of sustainability is one of the greatest challenges of our day.
2. In an era of heightened environmental concern, careful consideration must be given to food- and beverage-related business and agricultural practices, as well as lifestyle behaviors.
3. Ecological systems are now experiencing multiple severe and mutually reinforcing stresses, with the root causes of ecosystem changes being an increased per-person consumption of ecosystem services and a growing population.
4. Trends that will continue to disturb ecosystem functions include the increased demand for food, fiber, and water; ecosystem contaminants and waste; eutrophication of waterways; global trade; climate change; over-fishing, over-grazing, and over-logging; and habitat loss and fragmentation.
5. Ecological footprint calculations now consider the food system in understanding human impact on the living systems of the natural environment.
6. Removing trade barriers increases the amount of food entering a country, affects the types of foods being imported, and increases competition for local food producers.
7. Some scientists, healthcare professionals, and public health professionals encourage reducing animal product consumption while recommending improvements to overall dietary patterns.
8. The energy density of food has increased in recent years, as have snacking, soda consumption, and overall food intake.
9. Organizations and people work across a variety of disciplines and venues to improve the integrity of food systems and promote healthy lifestyle behaviors that reduce human impact on the living systems of the natural environment.
10. Many edible native plants have impressive nutrient profiles; in addition, native plants are extraordinarily beneficial to ecosystems and ecosystem services.

Issues for Class Discussion

1. Discuss the current trends that will continue to disturb ecosystem functions into the future, including increased global demand for food and water.
2. Discuss potential solutions for the problems that threaten our food and water supply, such as the following:[13]
   a. Ecosystem contaminants and waste
   b. Eutrophication of waterways
   c. Global trade
   d. Climate change
   e. Over-fishing
   f. Over-grazing
   g. Over-logging
   h. Habitat loss and fragmentation

Research Areas for Students

1. The multifaceted relationship between food production and the living systems of the natural environment
2. The connections among nutrition ecology, ecosystems, ecosystem services, and the concept of ecological footprint
3. A historical timeline of anthropogenic effects on the living systems of the natural environment
4. The relationship between diet and climate change, and the potential role of diet in mitigating climate change
5. Ways to reduce the impact on the living systems of the natural environment via nutrition ecology

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