Chapter 5

Mathematics: Food, Soil, Water, Air, Free Speech

As I write there are reports of yet another outbreak of *food borne disease* with some hospitalizations and deaths. This time it is *Escherichia coli* O157:H7, a virulent variant of the benign E. coli bacteria that resides in all of our digestive tracts. Extremely rare until 1982, 0157:H7 is not unusual today, [202]. According to a page at www.cdc.gov in 1999, more than 75 million Americans get sick each year from food, of which about 325,000 require hospitalization. At least 5,000 to as many as 9,000 die. The situation is not improved in 2009. I am not sure how this death rate compares to that of hunter-gatherers going after woolly mammoths, but it is not comforting. Let's do a U.S.A. warm-up exercise.

Exercise 5.1 Food-Borne Disease Roulette

(i) The population of the U.S. on July 1, 1999 was estimated to be 279,040,168. What are the chances of not getting sick from food that year? Hint: Consider $1 - \frac{75000000}{279040168}$. What does this number mean?

(ii) Assuming "the chances" do not change from year to year, what are the chances of going two years in a row without getting sick? Hint: Consider $(1 - \frac{75000000}{279040168})^2$. What are the chances of going a lifetime of 75 years in a row without getting sick from food?

(iii) What are the chances of going a lifetime of 75 years and not requiring hospitalization for food-borne disease?

(iv) What are the chances of going a lifetime of 75 years and not dying from a food-borne disease?

(v) Attempts to remove E. coli O157:H7 from meat involve treating with chemicals and/or irradiation, which likely will result in pathogens resistant to each. What is an emerging consensus as to the cause of the appearance of E. coli O157:H7 in the food supply, and what simple protocol would remove most of it? (Regarding the chemical treatment of ground beef with ammonia, see the front page article by Michael Moss, *The New York Times*, Dec. 31, 2009, pp. A1, A14. In particular I found the term "pink slime" describing processed beef interesting.)

(vi) A "typical" beef hamburger contains meat from how many different animals?

5.1 The "Hour Glass" Industrial Agriculture Machine

There are several serious food-borne diseases besides O157:H7, cf., [202]. Such food-borne illness can, for example, end in excruciating death or re-sign one to a lifetime of kidney dialysis or transplants. Less dramatic, but nevertheless impactful, say in the United States, are "western diet" related maladies such as obesity, diabetes, cardiac disease and cancer. Whether or not you believe that diet has anything to do with health or disease, there is a definite *pattern* that has come to dominate the "food system" of industrialized entities such as Europe or the U.S.A. This is called the *"Hour Glass" Industrial Agriculture Machine*, cf., [521, p. 13]. If this machine provides your food, and it probably does, you should take note that it has an "Achilles heel;" it runs on fossil fuel. Fossil fuel supplies follow a Hubbert's Peak graph, cf., Section 1.7.

The "Hour Glass,"for the U.S. for example, has at its top, as an order of magnitude, 10^6 farmers, those who grow the "inputs." At the base of the hour glass are an order of magnitude 10^8 consumers. In between there is a narrow neck in the machine consisting of, in order of magnitude, 10^2 to 10^4, *central decision makers.* In some subsets of this machine things are even more extreme. For example, in 2009 in the U.S. the four largest beef packers controlled about 84% of the market, and close to half of all supermarket food was sold by five corporations, Wal-Mart being the largest by far.[1]

You are most likely to encounter this machine in a supermarket; unless, for example, you happen to belong to the approximately 49 million Americans living with hunger or food insecurity, or the 1.02 billion people worldwide who

[1]In 2000 the top ten agrochemical companies (seven of which are U.S. corporations) controlled a majority of the market in global food production, see [71, page 187], [489, 291]. The seven U.S. corporations in 2002 were Philip Morris, ConAgra, Mars, IBP, Sara Lee, Heinz, and Tyson Foods. (Tyson has since bought IBP.) Ranked first was Nestlé, of Switzerland, ranked third Unilever, of the U.K./Netherlands and ranked sixth Danone, of France. In the U.S. in 1997 just three companies, Philip Morris, ConAgra and RJR-Nabisco accounted for nearly 20% of all food expenditures, [489]. Philip Morris (at one point was reorganized as a subsidiary of the holding company Altria Group, Inc.) owns hundreds of food brands such as Nabisco (which it bought in 2000 for $14.9 billion) and Kraft. Nabisco and Kraft products include Post cereals, Ritz, Triscuit, Waverly, SnackWell's, Honey Maid, Premium Saltines, Planters, Nutter Butter, Chips Ahoy!, Newtons, Oreo, Cool Whip, Jell-O, Kool-Aid, Capri Sun, Miracle Whip, Philadelphia cheeses, Velveeta, Cracker Barrel, Maxwell House coffee, Starbucks, Grey Poupon, A-1, Oscar Meyer, and Tombstone Pizza, [348]. (On July 9, 2004 the British Broadcasting Corporation (BBC) announced that Philip Morris paid the European Union (EU) $1.25 billion to settle legal action of the EU against Philip Morris accusing them of collaborating to smuggle cigarettes into the EU to avoid taxes and duties. See also Associated Press article by Paul Geitner, July 10, 2004. Other tobacco companies were similarly accused.) This information is getting more difficult to find as the proportion of a market controlled by a single firm in a very concentrated market is considered proprietary information. Mergers and acquisitions frequently change (and usually further concentrate) ownership. I entered "consolidation" + "agriculture" into Google on July 7, 2004 and the first URL was [291]. In 2002 we had the following: Only two companies, Cargill and Archer Daniels Midland, controlled about 75% of the grain and corn that's traded in the world (Heffernan says in [292]); the three largest beef processors sell about three-fourths of the beef in the United States; the four largest pork processors handle 60% of the country's pork; and four companies process half the nation's broiler chickens. And so on through virtually every agricultural sector.

are undernourished.[2] Many poor do not have easy access to "the supermarket" with its apparent cornucopia of options, cf., [1].

The relative few in control of most food have made a number of decisions of which we are not all aware. The U.S. 1938 Food, Drug and Cosmetic Actsaid that any product that was an imitation of a standard food, like bread, milk, cheese .... had to be labeled "imitation." The FDA (without a vote of Congress) in 1973 repealed the 1938 rule, and an imitation food did not have to be so labled as long as it was not *nutritionally inferior* to the food it was imitating. You can guess how "nutrition" was (is) defined.[3]

In 1958 an amendment to the Food, Drug, and Cosmetic Act of 1938, The Delaney Clause, named after Congressman James Delaney of New York, said: "the Secretary of the Food and Drug Administration shall not approve for use in food any chemical additive found to induce cancer in man, or, after tests, found to induce cancer in animals." The Food Quality Protection Act of 1996 exempted pesticides from the Delaney Clause, as long as the pesticide amounts were "safe."

In the U.S., by means of the "revolving door," cf., Exercise 4.9, between industry and the FDA, genetically engineered entities were declared "substantially equivalent" to their unengineered counterparts.[4] Thus there never has been a public discussion in the U.S. or vote of Congress about this declaration of equivalence. Of course, there is a logical contradiction here, since all genetically engineered entities have patents which can only be granted if the thing patented is substantially "new." Are GMOs new enough to be tested for safety or anything else, say nutritional content? Are GMOs new enough to be labeled as such in any way whatsoever?

The food industry does lobby the U.S. Congress, for example, and every 5 to 7 years a "farm bill" is passed which has profound consequences on our food supply – and international relations![5] One of these consequences was brought to the public's attention in [543], viz., a majority of the products in the typical supermarket are *some form of corn.* (See also www.kingcorn.net.)

[2]The 49 million figure was announced by the United States Department of Agriculture (USDA) on November 16, 2009, cf., *The New York Times*, Nov. 17, 2009, p. A14. There were officially 307,958,472 people in the U.S. on Nov. 18, 2009. The 1.02 billion figure was announced by the United Nations Food and Agriculture Organization (UNFAO) on Oct. 14, 2009.

[3]A solid argument can be made that "nutrition science" is still quite primitive and that it cannot now, and perhaps never will be able to, understand all the essential properties of food – that it cannot, for example, really make the determination that imitation bread is equal as a food to real bread.

[4]Thus GMOs, genetically modified organisms, are GRAS, generally recognized as safe, without special review. For an entertaining documentation of this fact see: the DVD "The World According to Monsanto," a Marie-Monique Robin film, and the DVD "Food, Inc.," a Robert Kenner Film. Also [488, Chapter 7].

[5]When subsdized U.S. corn, selling for below the cost of production, is imported into, say Mexico, thanks to NAFTA (the North American Free Trade Agreement), small farmers cannot compete and end up going to cities (or some other country) looking for work. This is one force contributing to the world-wide growth of slums, cf., [129].

When corn and soybean prices are kept below the costs of production by farm-bill policies – read subsidies – they are an attractive resource. Massive U.S. government subsidies have been paid to corn farmers, e.g., $9.4 billion in 2005, and $50 billion over a decade. And the majority of subsidies in general do not go to "small family farmers," e.g., in 2003–2005 two-thirds of subsidies went to one-tenth of U.S. farmers. While the number of "microfarms" have recently begun to increase, perhaps out of necessity; large farms still dominate food production. In 2002 144,000 farms produced 70 percent of the nations food. In 2009, 125,000 farms did so – about 6 percent of the total number of farms. Just one of the implications for the cash strapped consumer is that, for example, between 1985 and 2000 the real price of fruits and vegetables increased by 40% while the cost of "liquid candy," i.e., soft drinks with high fructose corn additive, decreased by 26%. Small farmers in the U.S. and elsewhere cannot compete with such a system, unless they are very clever and lucky (more on this later), cf., www.usda.gov, www.ewg.org, [323].

Exercise 5.2 Supermarket Surprises

(i) If you live in the U.S. estimate the amount of money you have already paid in taxes that is embodied in the "real cost" of a 2 litre bottle of soft drink (with high fructose corn syrup).

(ii) From [544, p. 117], corn contributes 554 calories (Note: We will discuss calories in more detail in VII.) a day to America's per capita food supply, soy 257 calories, wheat 768 calories, and rice 91 calories. Compare your diet and estimate the fraction of your daily calorie consumption that comes from these 4 "seeds." An easier version of this problem is to check the ingredient lists of the foods you eat for the presence of these four, or substances derived from these four. For example, Ghirardelli Premium Baking Double Chocolate Bittersweet Chips contains "soy lecithin – an emulsifier," but no corn on the list.

(iii) Whether or not you are a vegetarian, estimate the amount you have already paid in taxes that have become subsidies for a pound of beef, a pound of pork, and a pound of chicken. Assume that all three are "factory farmed," cf., [352].

(iv) Count the total number of varieties of apples, oranges, and other fruits available to you at your local supermarket. Do the same for vegetables. Is the production of fruits and vegetables subsidized in the U.S.?

(v) Count the number of varieties of breakfast cereals available. Count the number of varieties of cookies and other baked goods. Count the number of varieties of candies. Compare their ingredient lists.

(vi) How many manufactured foods in your supermarket are "imitation food" as defined by the original 1938 act mentioned above? How many ingredients are synthetic chemicals? How many such synthetic ingredients did not exist, say, 100 years ago?

(vii) What fraction of the products in your supermarket have genetically engineered contents? (The answer may surprise you.) Why are they not labeled as such in the U.S.? Note that all of Europe, Great Britain, Australia, Japan, and Russia have strong labeling laws, cf., [497, p. 63]. What supermarket items are you fairly confident do not contain genetically engineered ingredients?

(viii) I claim that if a processed food in the U.S. contains corn or soy in some form, then the chances that you are eating genetically engineered food (at least partially) is quite high. Investigate this claim. Investigate what is known about potential effects of genetically engineered corn and soy, cf., [644].

(ix) Artifical flavors are key ingredients in manufactured food items. Have you ever heard of the company *Givaudan*? It apparantly manufactured the vanilla flavor for Coca-Cola, cf., "The Taste Makers: The secret world of the flavor factory," by Raffi Khatchadourian, *The New Yorker*, Nov. 23, 2009, pp.84–99. This fact was apparantly a carefully guarded secret for some time until it was accidentally revealed to a reporter. That is not the only closely guarded secret; try to find out the chemical composition of any of the flavorings used in manufactured food. What is the role of the FDA here? *Virginia Dare* is another "flavorist" corporation. How many flavorist corporations can you find? There must be several, since there exists the Society of Flavor Chemists. Is there a difference between "natural" and "artificial" flavors? According to a flavorist quoted in the article cited, it is not practical or economical to use "real" foods to add flavor. What proportion of your diet consists of "real" food?

(x) Does the length of the supply chain for particular foods affect the content of those foods?

5.2 Industrial Agriculture Logic vs. the Logic of Life

The reader might think perhaps that only mathematicians could be concerned with the subject of this section; however, I will show that Nature indicates that logic, in a form to be discussed, matters. Thus humans who eat should pay attention. We start with one difficulty; humans cannot define life, cannot create life (despite patents to the contrary) from scratch, and do not understand life in all of its complexity. In short, for the time being, *life* is bigger than mathematics; it is beyond human understanding. However, some facts are settled and generally accepted by scientists at this time.

CHNOPS: Atoms, Molecules, Cycles, Photosynthesis and Trophic Levels. Matter, i.e., "stuff," is composed of chemicals; the smallest unit of a chemical is called a *molecule*. Chemicals are composed of *elements*, which are listed in the Periodic Table, page 253. The smallest unit of an element is called an *atom* of that element. The typical human body has at least 60 of these elements; but as noted in [68, page 30], there are six elements that seem particularly important to life: C, carbon; H, hydrogen; N, nitrogen; O, oxygen; P, phosphorus; and S, sulphur; CHNOPS for short. (The alert organic chemist will point out that since the time of Justus von Liebig in the mid 19^{th} century, N, P *and* K, potassium, have been considered essential nutrients/elements for life.) Life creates proteins, fats and carbohydrates, as has been known since the early 19^{th} century. There is a large nuclear fusion reactor, called the *sun*, which provides the energy for almost all life on earth, via a process called *photosynthesis*; whereby green plants take inputs of carbon dioxide, CO_2, and water, H_2O and solar energy, and produce outputs of $C_6H_{12}O_6$, glucose, and molecular oxygen, O_2, viz.,

$$6CO_2 + 6H_2O + Solar\ Energy \longrightarrow C_6H_{12}O_6 + 6O_2.$$

I said "almost all life" in the sentence preceding because there are forms of life that do not depend on photosynthesis but on *chemosynthesis*. For example, *chemoautotrophic bacteria* create the outputs for their life, viz., sugar and sulphur compounds, with inputs of carbon dioxide and hydrogen sulfide in hot thermal vents in certain places at the bottom of the ocean. You can follow developments such as the recent discovery of 170 new chemosynthetic marine species at www.coml.org, the Census on Marine Life. Although some believe that life on earth may have originated "chemosynthetically," today most life, including human life, ultimately depends on photosynthesis. Humans also use energy extracted from fission reactions and fossil fuels, but fossil fuel energy is actually fossil solar energy; and fission and fossil fuel energy are subject to Hubbert's Peak mathematics. One heretofore miminally exploited source of energy is geothermal, i.e., heat from earth.

Plants are participants in the *food web*, as are all living organisms. Any living organism is edible by (or otherwise can be assimilated by) other living organisms. So the food web has many *cycles*. The Axiom on Matter Cycles, page 56, thus can be refined into many subcycles: the carbon cycle, the water (hydrological) cycle, the nitrogen cycle, and so on. When one organism, call it the predator, eats another, call it prey, only a fraction of the prey's energy is useful for the predator. Thus a constant external supply of energy (from the sun) is required to keep the food web running.

In [503, Chapter 13] and [270, Chapter 1], and many other references, we see that food webs are organized acccording to *trophic levels*, based on who eats whom. In a simple model a green plant is assigned trophic level 1, a herbivore a trophic level 2, a carnivore that eats herbivores a trophic level 3 and so on up a food chain in the food web. Complications can easily arise, as in the case, for example, wherein a herring's diet may be half algae and half herbivorous crustaceans. Such a herring would be assigned a trophic level of $2\frac{1}{2}$. As a rough rule of thumb, which is often not accurate except to the nearest order of magnitude, it takes 10 units of energy, say 10 calories, at one trophic level to support 1 unit of energy, or 1 calorie, at the next higher trophic level. In many diverse ecosystems and in many predator-prey relations there are about 90 kilograms of predator to every 10,000 kilograms of prey. When bacteria "eat" a lion or a wolf a cycle is completed. Are bacteria predators?

Interestingly there are other mathematical invariants associated with the food web. For example, as the CHNOPS elements flow from one organism to another, they remain in a fixed ratio, [68]. (You might investigate the closely related subject: Redfield Ratios.) For every C there are so many Hs, and so many Os and so on. This is an indication of a close connection among all living organisms.

Exercise 5.3 CHNOPS and the Elements of Life

(i) In the chemical equation (which chemists call a stochiometric equation) for photosynthesis, check to see that the number of atoms of C input (on the left side) equals the number of atoms of C in the output (on the right side). Do the same for O and H.

(ii) Find the relative ratios of the elements C, H, N, O, P and S in living organisms.

(iii) Do the same ratios apply to both photosynthetic and chemosynthetic life forms?

Soil is a Living Community. First, whatever life is, *soil* is a living community. As hunter-gatherers we could probably skip being concerned about the soils of the earth and just let them take care of themselves, cf., [537, Chapter 6]. However, about 10,000 years ago, humans invented *agriculture*. The process was not entirely smooth, from [236, p. 100]: *"After the invention of agriculture, most people were **worse off** than their ancestors. From skeletons we know that when agriculture arrived, average height declined about 4 inches, from $5'9''$ to $5'5''$ for men and from $5'5''$ to $5'1''$ for women. Compared to hunter-gatherers, farmers work harder, eat a less nutritious diet, and get sick more often."* The social structures and power relationships that agriculture enabled are a fascinating subject of study, and understanding them would probably shed much light on the current social structures associated with the Hour Glass Industrial Agriculture Machine – consider such a study an exercise.

Although non-soil based agriculture exists, for example, hydroponics and aquaculture (like fish and shrimp farming), they are resource intensive and face fundamental problems likely to prevent them from significantly replacing soil based agriculture. Consider it an exercise (for which I do not have a solution!) to figure out a way to "feed the world" without soil. (One candidate is to live off of farmed algae!) I will proceed under the assumption that we need topsoil for agriculture.

Humans cannot create life from scratch, neither can we create soil. Under tropical and temperate agricultural conditions, it takes 200 to 1000 years to form a 2.5 cm (about 1 inch) depth of topsoil. This one inch of topsoil is equivalent to about $\frac{340\ tons}{ha}$, where ha stands for one hectare, or $10^4\ m^2$, cf., [537, p. 152]. We can encourage topsoil formation, but we remain dependent on processes of Nature to create soil, just as we are dependent on processes of Nature to create life. There is a conflict between the logic of industrial agriculture and the logic of life/Nature: *Industrial agriculture mines topsoil. After each farming cycle, there is less topsoil than there was at the beginning.* Unfortunately, the collection of folks destroying topsoil faster than it is forming includes many who are not totally part of industrial agriculture.

In most nations the average rate of topsoil loss is between 20 to 40 $\frac{tons}{ha-yr}$. (Note: $tons/ha/yr$ is the same as $\frac{tons}{ha-yr}$, see Exercise 5.4.) However, $\frac{3600\ tons}{ha-yr}$ has been observed. In the U.S. the topsoil on average is being eroded at a rate of $\frac{13\ tons}{ha-yr}$, while it is being regenerated at a rate of $\frac{1\ ton}{ha-yr}$. Over all, at least one-third of the topsoil in the U.S. has been lost during over a century of farming – it is estimated that Iowa, a state with some of the best soils anywhere, has lost half its topsoil during this time. Worldwide more than $10^6\ ha$ of agricultural land are lost every year due to soil degradation; and during about the last 40 years of the last century 30% of total world arable land has been abandoned due to lack of productivity ($10^8\ ha$ of this in the U.S.). There are other processes ending in loss of agricultural land. For example, in the 30 year period 1945–75 an area of ag-land in the U.S. the size of Nebraska was covered with roads, homes, and factories. And this process continues year after year. See [537, 173].

This cannot continue indefinitely, consider the following exercises.

Exercise 5.4 Loss of Topsoil and Agricultural Land

(i) Topsoil regeneration in the United States is on average 1 $ton/ha/yr$. How much is this in inches or centimeters? Do you think you would notice this? Can you show that $\frac{1\ ton}{ha-yr} = 1\ ton/ha/yr = \frac{(\frac{1\ ton}{ha})}{yr}$? Are any of these the same as $\frac{1\ ton}{(\frac{ha}{yr})}$? See II.

(ii) If topsoil loss is $\frac{13\ tons}{ha-year}$, what is this in inches or centimeters? Do you think you would notice this?

(iii) Would you notice a rate of topsoil loss of 3600 tons/ha/year?

(iv) In the U.S. about 50 *liters* of oil equivalents are expended per *ha* to compensate for cropland degradation, cf., [537, p. 293]. If fossil fuels become unavailable, what do you propose will happen (or should have happened)? What are fossil fuels used for in industrial agriculture?

(v) If half the topsoil in Iowa has eroded away in the past century or so, what will happen in the next century? Will the agricultural pressures on the lands in Iowa increase or decrease in the next century?

(vi) Any process that removes organic matter from agricultural land probably contributes to soil loss. What does this imply for biofuels, i.e., making substitutes for oil using corn, wheat, soy, even grass? If food grains are used for biofuels, what effect will this have on food supplies, food prices, availabity of food for the poor (or the more well off)?

Exercise 5.5 Some Global Numbers

In [537, p. 155], we read that in 1992, the year I started teaching this course, worldwide agricultural ecosystems covered about 50% of the world's (ice-free) land area. Forest ecosystems covered about 25% and human settlements covered about 20%. The total area of the earth is $5.10(10^{14})\ m^2$. The total area of ice-free land is $1.33(10^{14})\ m^2$.

(i) About how many hectares were used by humans for agriculture in 1992? What percentage of the total area of the earth is this? Do you think the land best suited for agriculture was cultivated first? What does this say about the future?

(ii) About 10^7 *ha* of agricultural land is abandoned each year due to serious soil degradation; is this significant? Where do you think people have gone to find replacements for this abandoned land?

(iii) What percentage of ice-free land is left unmanaged by humans, i.e., "wild"?

(iv) The human population of the earth in 1992 was about 5.5 billion, i.e., $5.5(10^9)$. In 2009 it was about $6.8(10^9)$. What do you think human use of the world's ice-free land area would look like if the world's human population were $11(10^9)$? Do you foresee any possible problems?

(v) Around the world, in North America, Europe, and parts of Asia, honey bees have been experiencing dramatic declines. The term CCD or colony collapse disorder has been used to describe this phenomenon. Research the health of the world's bee population at the time you read this. Have definitive causes for CCD been arrived at? Bees are important for the role they play in pollination, in fact, about a third of the modern diet relies on bee pollination. (For example, dairy cows are fed alfalfa which is pollinated by bees.) How are non-domesticated bees doing by the way? (Not well, last time I checked.)

The *Green Revolution* of the last century brought fossil fuel dependent (herbicide, insecticide, synthetic fertilizer) agriculture to the entire world. Global trade and institutions such as the World Trade Organization (WTO) together with the subsidies that industrial agriculture enjoys have made it difficult to grow food outside of the industrial model. This is because the central decision makers in the neck of the "Hour Glass" have written the rules. Small farms in the U.S. and around the world are under increasing pressure from industrial agriculture. For example, the industrial system is making it increasingly difficult for farmers to keep their own seed, a practice that is over 10,000 years old and once the source of literally boundless variety of locally adapted plants, and individual freedom for farmers. Amartya Sen, Nobel Laureate and economist, points out that 80% of all malnourished children in the developing world in the early 1990s lived in countries that boasted food surpluses – surpluses of luxury foods grown for export on land that could have grown subsistence crops to be eaten locally. Farmers increasingly find a limited number of buyers for their products. Farmers around the world go into debt, work hard, yet lose land that has been in their family for generations. Some become contract workers on land that was once theirs; thousands each year choose suicide. Many are displaced to urban areas, often slums. A few choose rage, cf., [159]. For the moment, industrial agriculture dominates the world food system. How many farmers or consumers are free to choose to be part of a food-system that is independent of industrial agriculture? Perhaps surprisingly there still remain millions of small farmers around the world (Latin America with 17 million farms, Africa with 33 million farms, Asia with well over 100 million farms, almost all less than 2 *hectares*) who survive using their intimate knowledge of the land, their locally adapted seeds and animals, and their cultural connections with domestic markets, cf., [36, pp. 16–7]. The total yield per hectare of these completely integrated small farms is substantially greater than that of any monoculture enterprise, cf., [36, p. 139]; but their strength – diversity – makes them practically invisible statistically in terms of output of any single crop. The logic of diverse, integrated agriculture more closely mimics the logic of Nature. The remaining sections of this chapter continue to address the logic of Hour Glass Industrial Agriculture machines.

5.3 Fast Foods, Few Foods, and Fossil Fuels

Food and the Air. It is fairly well known that industrial agriculture is one of the largest sources of global warming gases, cf., Exercise 1.10. For example, according to the IPCC, agricultural land use contributes 12% of global greenhouse gas emissions just from methane and nitrous oxide (each more potent in trapping heat than CO_2). In the United States, agricultural use of chemical fertilizers, herbicides and fossil fuels contributes nearly 20% of U.S. CO_2 emissions, cf., [247, p. 204]. These are important data, but what really makes an impression on me is seeing the local effects on the air of industrial agriculture. Take a prodigiously productive area like the San Joaquin Valley in California, home to some of the dirtiest air in America. From [113, pp. 155-6], (Fresno is a city in the Valley), *"The San Joaquin Valley – the most prolific farm belt in America – may be the most dangerous place in the United*

States to breathe." (*The Fresno Bee*, December 2002) From the investigative series by *The Fresno Bee* we learn that: Farming *"creates more lung-searing air pollution than the Valley's eight highest-polluting large businesses combined."* Farms produce more than half of the region's particulate pollution, with heavy machinery plowing huge tracts of eroded monocrop land. Not even Los Angeles has more violations of daily or long-term air safety standards. Fresno County has California's highest rate of childhood asthma. *"The air, laced with some of the nation's highest concentrations of chemical particulates and dust, is a serious health hazard ... Medical experts, who have connected these particles to higher death rates, fear these specks are more dangerous than ozone or smog."*

Food and Water and Free Speech. A *dead zone* in the coastal waters of a continent (or in a lake) is an aquatic environment which lacks sufficient dissolved oxygen to support fish life. Although some occur naturally, the number of dead zones has been increasing, approximately doubling every decade since the 1960s, along with the increasing intensity of industrial agriculture and urbanization. (In fact, animal-factory farms *are equivalent* to large cities, some as large as Los Angeles, say, in terms of sewage generated. Farming in the United States is responsible for 70% of water pollution, cf., [91, p. 29].) Chemical fertilizer and sewage runoff contain soluble nutrients (such as nitrogen and phosphorus) which cause *eutrophication*; fertilized water gives rise to algal blooms which deplete the oxygen. As of 2008 there were 405 dead zones worldwide, cf., http://www.epa.gov/msbasin/pdf/diaz_data.pdf. Dead zones vary with time in size depending on environmental conditions. Perhaps the most famous, but unfortunately only one among many, dead zones in the U.S. is the one at the mouth of the Mississippi River. In the news media its size is often compared to the size of the state of New Jersey, 8,729 square miles. The scientific literature records a size of "more than $22,000\ km^2$." Are these roughly the same?

In a factory farm the animals, be they pigs (hogs), chickens, turkeys, or cows, by definition live their lives remaining approximately in place, eating food laced with antibiotics, urinating and defecating. The antibiotics are administered regardless, even when the animals are not sick, since animals gain weight slightly faster on a diet laced with these drugs. Aside from the fact that some consider this a form of pollution of the resulting product, such a practice has already resulted in bacteria which are immune to an increasing number of antibiotics. For example, some pathogenic bacteria in ground meat have been found to resist treatment by as many as 12 antibiotics, cf., [488, p. 177]. It is a near mathematical certainty that more and more bacteria will become immune and/or resistent to larger and larger classes of antibiotics, if we continue to expose them routinely and broadly to antibiotics – that's how Nature works![6] This process of bacteria becoming antibiotic resistant

[6] Overuse of antibiotics in humans and animals led to drug-resistant infections that killed more than 65,000 people in the U.S. in 2009 – more than prostate and breast cancer combined, cf., Associated Press article by Margie Mason and Martha Mendoza, Dec. 29, 2009.

cannot be stopped entirely, but it can be slowed down considerably by greatly restricting the number of antibiotic exposures bacteria are given from which they can "learn" resistance. Review some history to see what life was like before antibiotics; it will likely motivate you.

Did you ever wonder what happens to animals that die before, or get too sick to make it to, slaughter? Most often they are *rendered*. Typically a fork lift or loader puts the carcass on a truck; and it is hauled to a rendering plant, where the remains are processed into a wide variety of products. So far, this is economical and rational. However, lifelong rancher Howard Lyman pointed out to Oprah Winfrey on her April 16, 1996 show on "Dangerous Foods" that sometimes sick cows are rendered and fed back to cows – in effect making cows cannibals! Since Europe had not long before had a "Mad Cow" experience, i.e., BSE, bovine spongiform encephalopathy, cf., [561, 587, 617], where people were infected with a *prion* disease, the study of which gained Stanley Prusiner the 1997 Nobel Prize in Medicine, beef prices dropped for a short time. This is because if a cow infected with BSE is rendered, and fed to other cows, the disease could spread exponentially. (This practice was banned by the U.S. government in the late 90s; however, rendered cows could still be fed to pigs and chickens. I am not sure how many inspectors there are monitoring/preventing illegal acts in this regard. Have there been any prosecutions?)

Now in 13 states, including Texas and Colorado, it is illegal to make disparaging comments about food. These laws are clearly unconstitutional, an abridgement of free speech and the press. Under these laws Rachel Carson, and her publisher, could have been sued for *Silent Spring*, same for Upton Sinclair and *The Jungle*, or *Consumer Reports* for telling us about pesticide residues on foods measured in their labs. Oprah was sued in Texas, Texas Beef Group, et al. v. Oprah Winfrey, for millions of dollars. Luckily Oprah Winfrey is a billionaire with principles who fought the law suit for years; it cost her millions of dollars, but she finally won. Unfortunately the legal process stopped short of the Supreme Court where such laws could be declared unconstitutional – hence they are still on the books! Thus since Colorado has one of the most repressive "Food Disparagement Laws" in the country – making "disparaging" comments about food a crime with possible incarceration – MartyWalterMath.com LLC could be sued for writing this book. Truth and documentation matter little if you are sued and you do not have the money to fight it – so much for the First Amendment to the Constitution of the United States of America for most of us. Estimate how many column inches in newspapers, or how many books or radio and television shows addressing food safety have not appeared because of these and other threats.

But let's get back to sewage. The amounts generated are enormous and concentrated. A 1997 estimate of total U.S. cattle, hog, chicken and turkey manure was 1.3 billion tons a year. That is 5 tons for every U.S. citizen – 130 times the excrement American humans produced per year, cf., [113, p. 179–80]. You could make a project of documenting pollution of ground water, rivers, lakes and coastal oceans from this factory farm manure. For example, factory-farm-caused fish kills have become epidemic in 10 states, with more than 1,000 documented manure spills wiping out 13 million fish between 1995 and 1998. Look up *Pfiesteria piscicida*, an organism which can be found in manure, which the EPA estimated has killed more than 2 billion fish in the rivers, estuaries, and coastal areas in the Chesapeake Bay region of North Carolina, Maryland, and Virginia, cf., [113, p. 179]. As early as the 1970s one of the first dead zones was identified in the Chesapeake Bay region.

No amount of academic citation of statistics can match the visceral experience of visiting a factory farm – a "chicken house," a "hog farm," or a cattle feed lot – and taking a deep breath. It does not have to be this way. Farm animals can be a pleasure to be around under more "natural" conditions. (The word "natural" has little, if any, legal meaning.)

Monocultures are Risky. The logic of industrial agriculture embraces *simplicity* versus the *complexity* of Nature. Nowhere is this more evident than in the ever larger areas planted in single crops, called *monocultures*, managed with fewer people, fewer steps, and bigger, faster machines. Example: Humans have selected as a principal source of food among the boundless varieties of food plants possible, a genetically engineered (more on this in the next section) variety of soybean whose primary recommending characteristic is the fact that it can be sprayed with a broad spectrum herbicide, most likely glyphosate or Roundup^{TM}. Such soybeans do not in general increase yield, cf., [265], but such a field of soybeans can be sprayed with glyphosate and all other plants, i.e., "weeds," are killed, leaving just the soybeans. In the span of a few years they now, as of 2009, are planted on 90% of the land in the U.S. devoted to soybeans, cf., [265]. The small army of laborers who just a few years ago were employed pulling weeds in soybean fields have been replaced by fast machines, often airplanes, spraying herbicide. The result is relatively speaking an ecological desert, where, for example, bees can no longer find as many "weeds" as they once "farmed" for pollen and nectar. Despite claims that herbicides do not significantly negatively affect the community of life that is soil and other organisms, there is evidence to the contrary.[7]

Studies have shown that glyphosate can kill fish in concentrations as low as 10 parts per million, that it reduces the growth of earthworms and increases their mortality and that it is toxic to many of the micorrhizal fungi which help plants take up nutrients from soils, cf., [9, pp. 24-5]. Even the long used synthetic nitrogen fertilizers have unintended consequences on the soil,

[7](http://www.esajournals.org/doi/abs/10.1890/04-1291) Roundup heavily impacts amphibians, THE LETHAL IMPACT OF ROUNDUP ON AQUATIC AND TERRESTRIAL AMPHIBIANS by Rick A. Relyea; (http://farmindustrynews.com/news/farming_multiplying_microbes_glyphosate/) Multiplying microbes - Glyphosate boosts Fusarium levels in Missouri study. Apr 24, 2001 12:00 PM, Gil Gullickson; (http://www.organicconsumers.org/ge/monsanto_fungus.cfm) Monsanto's Roundup Herbicide May Be Spreading Deadly Fungus August 23, 2003 by Jeremy Bigwood; and http://www.abcbirds.org/abcprograms/policy/pesticides/Profiles/glyphosate.html.

in that they stimulate not only plant growth but the growth of carbon-hungry bacteria in the soil – decreasing soil carbon content, cf., [247, p. 212].

Also, 63% of the U.S. corn crop is genetically engineered, cf., [265]. Some of the details of a critique of this corn differ from the one above of Roundup^{TM} resistant soy; but the basic conflict with Nature's logic remains the same. *Humans are selecting food crops based on an extremely limited number of variables.* This locks the agricultural system into perpetually engineering new plants adaptable to changing environments, while simultaneously reducing the diversity of plants to work with. The system is also locked into chemically dependent cultivation regimens that require fossil fuels. It locks the industrial farmer into dependence on a decreasing number of corporations and diminishing fossil fuel reserves. It is highly unlikely that such a system can be sustained in the long run.

Most folks have heard of the Irish potato famine of 1845, which resulted because the Irish planted a monoculture of potatoes; they relied on one variety. When a serious, lethal disease arrives to attack vast fields of identical plants, they all die together. The usefulness of diversity is obvious. The potato famine was not unique in the annals of major monoculture crop failures; there was at least one such in each of the following years: 900 A.D., 1845, 1860, 1865, 1890, 1916, 1954, 1969, 1970 (twice), 1984, 1989, ..., cf., [386, p. 100].

A multitude of small independent farmers over many generations have developed literally a boundless variety of food crops specifically adapted to their local areas: corn(s) in Mexico, potato(es) in South America, rice(s) in India and so on; and luckily millions remain around the world, cf., page 107. However, such diversity is under pressure. With each group of independent "peasant" farmers that loses their land, the varieties of food and the accompanying knowledge handed down to them over generations is lost as well. As previously undeveloped land is transferred to "development," wild species that might help diversify our food supply are often lost. The chilling story is told in *The Last Harvest: The Genetic Gamble that Threatens to Destroy American Agriculture*, by Paul Raeburn, [559].

Just like the production lines at the meat packing plants that are processing animals at ever increasing rates, the Hour Glass Industrial Agriculture machine runs faster and faster. The term *Fast Food* gains a whole new meaning. The central decision makers manufacture food faster and faster at the expense of complexity, diversity, and, I claim, sustainabity, because they can and it appears profitable – for now.

Exercise 5.6 Industrial Agriculture Converts Fossil Fuel to Food

(i) List all the ways that you can think of that fossil fuels are used to produce food in the industrial agricultural system. Then make your own estimate of the number of calories of fossil fuel energy needed to put one calorie of food energy on your plate. Does the order of magnitude of your answer agree with mine, viz., order of magnitude is one, hence the ratio is $10^1 = 10$? That is, *it takes 10 calories of fossil fuel energy to put one calorie of food on your plate.*

(ii) There once was a disagreement between two students in my class: one was from a ranch in Wyoming, another from the city of Denver. For a project one calculated the fossil fuel energy needed to put one calorie of deer meat on his plate (in his home at the ranch), where the deer was hunted on his ranch and stored in a freezer. The other (to make the math simple) calculated the fossil fuel energy used to put one calorie of potato on his plate (in Denver), where the potatoes were grown in Idaho within the industrial agricultural system. (Regarding storage, you can periodically ship potatoes, i.e., buy them at the supermarket, or process them.) Who do you think used more energy? If the potatoes were grown in a backyard garden in Denver, how would that change the calculations?

(iii) Which makes the greater contribution to global warming emissions: U.S. industrial agriculture or the U.S. transportation system (including cars, trucks, buses, and trains)?

(iv) Rich healthy soils are dark because of high carbon content. Green plants like grasses and trees with the help of the community of life in the soil (bacteria, fungi, and other organisms) sequester carbon from the atmosphere via photosynthesis. Suppose that it is true that the carbon in fossil fuels were mostly sequestered into the earth by green plants during the Carboniferous Period, from 360 million years ago to 290 million years ago. To the nearest order of magnitude this is 10^8 years. To the nearest order of magnitude we are burning these fossil fuels in 10^2 years. Thus, roughly, we are burning fossil fuels about 10^6 times faster than they were sequestered. If this is true, would restoring carbon to our soils globally by planting forests of trees and implementing restorative agricultural practices completely solve our "global warming problem?" Could the process of sequestering carbon in the soil be sped up with *biochar*, encouraging mycorrhizal fungi, rhizombium bacteria and subsidies to farmers that build soil? For example, see [389]. Are there other problems that planting forests and soil-restoring agriculture address?

(v) This exercise will help you get started on (i). Consider just one aspect of the *(synthetic) chemical dependency of industrial agriculture.* Globally over half of the nitrogen taken up by agricultural crops comes from *ammonium nitrate* fertilizer, created using natural gas energy using the *Haber-Bosch process*, cf., [81, p. xiv]. Natural processes such as bacterial action making nitrogen available to plants have been matched and exceeded, for the time being. Humans have thus created a global agricultural system that is not only fossil fuel dependent, it is (synthetically) *chemically dependent.* Many of the crops now grown were selected precisely because they respond well to synthetic fertilizers.

Plant fertilizers focus on three main ingredients: nitrogen, phosphorus, potassium. Estimate, or look up, global use of fertilizer for agriculture.[8] In particular, how much of this fertilizer is a synthetic chemical?

(vi) This will also help with (i). Estimate the distance traveled for each of the items of food on your plate. Most estimates of an "average" for food on an American's plate are over 1,000 miles. See, for example, [440, p. 425], [490, pp. 28–32].

(vii) What was the principal chemical Timothy McVeigh used to blow up the federal building in Okalhoma City in 1995? See [159].

(viii) There is an agency of the federal government that earlier was called "Animal Damage Control," or the ADC, and is now called "Wildlife Services." At the behest of agricultural interests this agency kills bears, bobcats, coyotes, wolves, eagles, birds of prey, pet dogs and so on, some by accident. Methods used include shooting from aircraft and poisoning devices using compound 1080. How many thousands of wild animals are killed

[8] For example, cf., *Vital Signs*, 2001, p. 33, WorldWatch.

each year by this unit? (You might be surprised that there are that many left to kill.) U.S. taxpayers paid $120 million for this "service" in 2008.

Exercise 5.7 Find an Industrial Polluter Near You

(i) Find the nearest sources, in time and space, of industrial pollution near you. Using the EPA's toxic release inventory (www.scorecard.org) you should be able to find one.

(ii) Find the nearest, in time and space, industrial agricultural polluter near you. For example, "Cargill fined $200,000 for clean water violations at Fort Morgan packing plant," by Howard Pankratz, *Denver Post*, posted to the web 11/13/2009; "Cargill plant pleads guilty to wastewater charge," Associated Press, *Denver Post*, web-posted 09/29/09.

(iii) Does an answer to (iii) also count as an answer to (i)? Can you quantify the pollution in some way? For example, from the Associated Press article mentioned in (ii): "Court documents show that Cargill violated its permit because it discharged more than 2,875 pounds per day of total suspended solids and more than 400 coliform colonies per 100 milliliters." (Question: How much more than 2,875 pounds/day?)

(iv) If you are feeling adventurous, find an industrial polluter that has not been exposed in the media.

(v) Industrial agriculture *adds* to the world's food supply and *subtracts* from the world's food supply in so far as it contributes to dead zones, such as in the Chesapeake Bay area, the mouth of the Mississippi river, off the coast of Oregon-Washington, the coast of California, and elsewhere (in the U.S. and world). Pick a dead zone and estimate the amount of food, e.g., fish, shrimp, oysters, etc, not produced because of dead zone conditions. Are there forms of agriculture that would not contribute to dead zones in bodies of water?

5.4 Genetic Engineering: One Mathematical Perspective

I was recently looking at a large ad in *The New York Times* from the biotech industry promoting genetically engineered crops – although the term *genetic engineering*, GE, was not mentioned. In fact, this terminology, along with *genetically modified organism*, GMO, have all but disappeared. The ad referred me to the web site www.whybiotech.com where you can see a sequence of videos and comments from quite credentialed folks in support of *biotechnology*. From a marketing standpoint who can be critical of *bio*, meaning life, and *technology*, which is almost synonymous in the public mind with progress and the "good life." But as with all advertising it is necessary to look beneath the surface and study the claims that are being made. (Note that in the following the word *transgenic* is synonymous with genetically engineered.)

The Question of Which Crops Have Higher Yields. A key attribute of any food crop is *yield*. By definition, yield is how much of the food in question is produced per unit area of cropland, measured in terms of kilograms or tonnes per hectare, or pounds or tons per acre. Yield is often measured in terms of volume, e.g., bushels per acre or cubic meters per hectare. The biotech industry clearly and consistently over the years has claimed that its GE crops have higher yields than non-GE crops with the implication spelled out for us that this will help the poor and hungry of an ever increasing global human population. No one I know is against solving the problem of world hunger! Biotech crops have been around in commercial production since 1996, so we should be able to look at the record and see if the claims of the ad with regard to yields is true. Unfortunately, it appears not.

A careful study must distinguish between two types of yield: *intrinsic yield* and *operational yield*. Intrinsic yield refers to the ideal (or maximum possible) yield of a plant under ideal conditions. Operational yield is the yield that is actually obtained by farmers in real life. A fairly comprehensive 2009 study of peer-reviewed research on yield of transgenics and non-transgenics by the Union of Concerned Scientists, www.ucsusa.org, [265], concludes: *"So far the record of GE crops in contributing to increased yield is modest, despite considerable effort. There are no transgenic crops with increased intrinsic yield and only Bt corn exhibits somewhat higher operational yield. Herbicide-tolerant soybeans, the most widely utilized GE crop by far, do not increase either operational or intrinsic yield."* A couple other references not mentioned in the above study included the following of Lappé and Bailey, [386, pp. 83–4], who checked up on Monsanto's 1995 claim that there was no "yield penalty" whatsoever in its GE soy: *"In 30 out of the 38 comparisons, the conventional variety outperformed the Roundup Ready^{TM} variety. The likelihood of such an outcome occurring by chance is less than 1 in a hundred. (Chi^2 = 6.95, df 37). Overall yield was down an average of 4.34 bushels for Roundup Ready^{TM} varieties, a statistically significant loss of just under 10% compared to conventional types. In only 4/38 instances did the Roundup Ready^{TM} crop approximate the yields of the highest yielding conventional soybean varietal type grain in the region."*

Ed Oplinger, Professor of Agronomy at the University of Wisconsin, has carried out yield trials on soybeans for 25 years. GE soybean had 4% lower yield than conventional varieties on the basis of data he collected in 12 states which (at the time) grew 80% of the U.S. soy.[9] I invite the reader to do his/her own literature search on comparative yields of GE corn, soy and Bt cotton, as well.

In the August 2009 of *Scientific American*, p. 28, there appears an editorial that I found surprising. The title of the editorial is "A Seedy Practice: Scientists must ask seed companies for permission before publishing independent research on genetically modified crops. That restriction must end." We read:

…"But agritech companies such as Monsanto, Pioneer and Syngenta go further. For a decade their user agreements have explicitly forbidden the use of the seeds for any independent research. Under the threat of litigation, scientists cannot test a seed to explore the different conditions under which it thrives or fails. They cannot compare seeds from

[9] Oplinger, E. S., Martinka, M.J., and K. A. Schmitz, "Performance of Transgenic Soybeans in the Northern U.S." (1999) Accessible in Adobe Acrobat format at http://www.biotech-info.net/herbicide-tolerance.html#soy. Benbrook, C., "Evidence of the magnitude and consequences of the Roundup Ready soybean yield drag from university-based varietal trials in 1998," (1999) Benbrook Consulting Services, July 13, 1999. RR-Soya-Yield-Drag.htm. These two references along with many others were found via (http://www.facebook.com/note.php?note_id=11293182509) "Soil Association: GM crops do not yield more - sometimes less," which was posted by The Soil Association.

one company against those from another company. And perhaps most important, they cannot examine whether the genetically modified crops lead to unintended environmental consequences."

"Research on genetically modified seeds is still published, of course. But only studies that the seed companies have approved ever see the light of a peer-reviewed journal. In a number of cases, experiments that had the implicit go-ahead from the seed company were later blocked from publication because the results were not flattering."

A group of 24 corn insect scientists (who have remained anonymous) sent a statement to the EPA – which could set open inquiry as a condition for approval of new seeds – protesting that

"as a result of restricted access, no truly independent research can be legally conducted on many critical questions regarding the technology."

A concise global overview of genetically engineered crops, with useful references, is [426, pp. 18–20]. Globally as of 2007 $114.3(10^6)$ *hectares* of crop land, half of that in the United States, was planted in GE crops, up 12% from 2006. Four cash crops account for virtually all GE production: soybean (51%), corn (31%), cotton (13%), and canola (5%). Globally 63% of GE crops are herbicide resistant, 18% insect resistant, with a combination of the two traits (called "stacked") accounting for the rest. In the United States GE crop production increased pesticide use 4% between 1996 and 2004. Monsanto GE crop traits are found in more than 85% of global GE crop hectares, and Monsanto controls 23% of the global proprietary seed market.

Note that reference [644] contains the results of studies on the health risks of genetically engineered food. Do you think this book would be thicker if the restrictions on research mentioned above were not in place?

Genetic Engineering: Some Basics. I am going to treat this subject rather abstractly so you do not need a degree in molecular biology to read it. I will introduce a minimal vocabulary needed to discuss the subject; but you can go on to pursue the subject in deeper detail, indeed you can major in it! Somewhat surprisingly, abstract mathematics probably has something very important to say about GE (genetic engineering), and the implications might not only be grand intellectually and ecologically but economically as well, to the tune of many billions of dollars.

You probably have heard of deoxyribonucleic acid, DNA, in a biology class or elsewhere. To a biologist a molecule of DNA is made by attaching building blocks of four types: Adenine, Thymine, Guanine, Cytosine – together in a "string." To a mathematician a molecule of DNA can initially be thought of as a (long) "word" spelled out with the letters A,T,G and C (with some geometry, including knots, included later). We will have some fun with these "words" by doing some DNA computing in IV.

Distinct regions of DNA contain distinct bits of information, and these specific regions of information are called *genes.* Living organisms are built up from cells (sometimes just one cell); and if said cells have a substructure, a membrane-bound bag, called a *nucleus* which in turn contains "packages" of DNA (plus the proteins that organize and compact the DNA) called *chromo-*

somes, then the organism is called a *eukaryote*. If the DNA in a cell is not packaged within a nucleus, the cell belongs to an organism called a *prokaryote*, of which there are two classes: Bacteria and Archea.[10] *Viruses* are "infectious agents" that can only replicate inside the cells of other organisms, and a virus has its own genes made from DNA or RNA (ribonucleic acid). *Prions*, which have no RNA or DNA are "infectious agents" that are essentially proteins that propagate by transmitting a mis-folded protein state. Thus geometry (and topology) arise in biology, not only in the double-helix of DNA, but in prions, and elsewhere! Prions are implicated in BSE, "mad cow disease."

The genetic information in the nucleus of a eukaryote is called its *genome*. Interestingly, most eukaryotes have one or more other little "membrane-bound bags" besides the nucleus, called *mitochondria*; and these have their own DNA, hence their own genome. The DNA in plant mitochondria can be 10 to 150 times larger than that of human mitochondrial DNA, [152, p. 276]. (Green plants also have *chloroplasts* with their own DNA.) Genes have a physical location, *gene locus*, and alternative DNA sequences in that locus are called *alleles* of that gene. You probably have heard of "dominant" and "recessive" genes, which are alleles. Later we will give a simple example of the mathematics involved and how this affects heredity. The *genotype* of an organsim is the complete genetic information of the individual, including specification of alleles.

The *phenotype* of an individual organism is the collection of its observable characteristics, sometimes called *traits*. The genotype of an individual is said to *express* itself to produce the individual's phenotype. The definition of "express" is not completely clear. This is a very important point, as we shall see.

Genetic Engineering: Lab Techniques. The idea is this. You have found an organism that has a trait you would like another organism to have. For example, a soil bacterium, *Bacillus thuringiensis*, *Bt* produces a crystalline protein which is toxic to certain organisms that attack corn. You would like corn to have this property. Using by now standard lab techniques, you can cut up the DNA of the *Bt* and isolate "the gene(s)" that "give" *Bt* the desired "trait." Copies of the gene(s) are cloned using established techniques, cf., [152]. Then a virus or bacterium is used to infect the corn plant and insert this gene into the DNA of corn. *Agrobacterium tumefaciens*, which produces galls in plants, is commonly used to do this step. Another method is to coat tiny gold or tungsten "microbullets" with the desired gene(s) and "shoot"

[10] The term prokaryote is a "failed term," as Norman Pace discusses in his paper, *Nature* 441, 289 (18 May 2006). Bacteria and Archea did not come "before," i.e., pro, eukaryotes, as gene sequence comparisons prove. Rather, Archea, Eucarya, and Bacteria are separate classes of life that radiate out from the "origin of life." They are not linearly ordered. Also defining something in terms of lacking a property, e.g., lacking a membrane containing genetic material, is not a sound practice. We have used the term prokaryote here with this warning and in the hope that it will be dropped soon.

them at corn cells with a "gun." Some of the bullets may make a lucky hit and get incorporated into the corn's DNA. In any event, a process that *randomly* inserts the desired gene into the DNA of the target will have a very low rate of success, i.e., most of the time the desired gene will not be taken up to produce a viable cell.

So there needs to be a method for finding any viable products of the above process. One common method is to attach a "marker gene" that confers antibiotic resistance if successfully inserted. In one case ampicillin resistance was used for transgenic corn, and for a transgenic tomato a kanamycin resistant marker was used. The cells are then grown in a medium containing the specified antibiotic, and only the ones with a "successful" implantation will survive.

There is one more thing: it has been found that "success" is assisted if a *promoter* is also inserted during the above process. The intention is that the promoter, very often coming from the DNA of *CaMV*, Cauliflower Mosaic Virus, will "turn on" the introduced gene and get it to express itself at high levels, [587, 9].

The whole process above of "engineering" is a lot less precise than the word engineering usually connotes. A lot of questions come to mind. For example, genes direct the production of proteins, and food allergies are reactions to proteins. The natural question to ask is, "Does any of this genetic engineering inadvertently create proteins that I am allergic to?" The politics, economics and science involved in this question are investigated in [497]; and I do not find the investigation comforting. *"Healthcare visits for food allergies in children nearly tripled between two time periods studied: 1992 through 1997 and 2003 through 2006. ... Asthma, eczema and hay fever are also going up."*[11] Before listing any more of the questions regarding GE food, let us look at the "logic" involved.

The Logic of Genetic Engineering. First of all, what is a "trait?" This is a very flexible (or fuzzy) term. It appears that there are traits, i.e., observable characteristics, that are simple and some not so simple. For example, "tall," "blue eyes," "red flowers," "produces *Bt* toxin" might be candidates for simple traits. Candidates for not so simple traits might be "aggressive behavior" or "yield" or "quality of seed." Through experimentation you can find genes that affect these traits, but what exactly is the relationship between a particular gene and a particular trait?

Not only is it an assumption, it is claimed to be a fact by the biotech industry that – for example – inserting the genetic material to create *Bt* corn, or glyphosate resistant soy does nothing else (negative) of significance. This is an example of *genetic determinism.* For each trait there is a gene, or group of genes, that express that trait in the phenotype – and it (they) does (do) not significantly affect other traits. (At least this is the hope if one does not mess

[11] "4% of U.S. children have food allergies, analysis finds," by Shair Roan, *The Los Angeles Times*, November 17, 2009. Increased levels of hygiene have been hypothesized by some as a cause; but rigorous long-term studies have not been done on this or the GE hypothesis.

with too many genes at once.) But we have seen evidence that the trait of yield is negatively affected in some cases, and intrinsic yield is not increased as claimed.

To my knowledge no one has isolated "the yield gene(s)" so it is not surprising that intrinsic yield has not gone up with GE crops – since that was not the object of that genetic engineering! The object was to get the plant to manufacture a pesticide, in the case of *Bt* corn, (*Bt* corn is registered as a pesticide); or it was engineered to be resistant to a herbicide. One can argue on general principles that the model of genetic determinism as described above is not complex enough to describe observed reality.[12]

There are many things to consider, and it would take an entire book to deal with a fraction of them. So I will stick with the following elementary observation that has to be explained away by believers in (simple) genetic determinism as described above. This version of genetic determinism is *reductionist* in the sense that the study is concerned with isolating single genes, attempting to reduce complexity to something far less complex, and then studying the simpler system. While this is a valuable tool in science (from which we have learned much, even about the genome), it perhaps is not adequate for understanding the big picture when studying truly complex, non-linear systems with synergy. In these cases, the "whole" is not only more than the "sum of its parts," it is sometimes totally different than the "sum of its parts (in this case, genes) taken individually."

I thus replace the simple view of genetic determinism with the *genome in synergistic context hypothesis*: the genome expresses itself by means of a complex, non-linear synergism with all other parts of the cell, including the genes themselves.

[12] From http://www.genome.gov we learn that human DNA, as a "word" in A, G, C, T is $3(10^9)$ letters long with 20,500 genes. (Initially it was predicted that there would be more than 100,000 genes in the human genome, but as more research was done this number has gotten smaller and smaller, with 20,500 the latest one available to me in 2009.) We also learn that the geonomes of any two people are more than 99% the same. Said differently, about 200 genes must account for the variability of *all* humans. This would be difficult to explain if one assumed the "linear," simple genetic determinism above. However, think of the genome *in context*, that is the genes are part of a cell where a true multitude of interactions of various combinations of genes among themselves and with other parts of the cell (don't forget the mitochondria, for example) are possible. Then, as we will see in IV, there are truly an astronomical number of possibilities; and it is no longer difficult to believe that all humans can share 99% of their genome, yet vary quite widely. (As an additional complication consider that it is known that "switches" exist that direct when and for how long given genes express themselves, with the result that a given gene can yield different phenotypic characteristics depending on when and for how long it is "turned on." Introducing *time as an additional variable*, with "on" and "off" states for genes allows for a great deal of additional complexity.) I call this the *genome in synergistic context hypothesis.* I also observe that if "playing" with 200 genes can result in observed human variability, playing with one or two genes in a plant might just have a lot more than one or two consequences. Maybe our connection axiom's corollary holds here with a vengence: in a complex system (like a cell) you cannot do just one thing!

I not only propose that the cellular context is important, I propose that to understand cells completely they must be studied in the context of the whole organism. And, that to understand the whole organism completely, it must be studied in the context of the environment of which it is a part! A grizzly bear in a zoo is a different system than a grizzly in the wild!

Thus the *context* in which genes express themselves ultimately includes the environment of which they are a part. It is entirely possible that this synergy is not a one-way street; I believe the environment can act on organisms, cells, and the contents of cells, including genes.

Thus I have set before you two paradigms for understanding how the genome expresses itself: the one presented to the public by the commerical biotech industry (I do not have access to any other presentations of this industry) and the "synergistic context" paradigm. The reader is free to choose. The science will have to catch up with the existing laboratory techniques somewhat before a rigorous determination can be made as to which view is closer to the truth. However, there are some interesting implications of the "synergistic context" view.

If the "synergistic context" hypothesis is true, then the whole basis of the patents held by the biotech industry can be questioned. For sure, the ingenious laboratory techniques should be (and are) patented. But the products of those techniques are not only not understood completely, they likely cannot be legally defined. The situation is analogous with some of the mortgages held by the financial industry during the financial crisis of 2008 and beyond, and the accompanying mortgage crisis. In some cases the financial industry could not prove (in the legal sense) who owned a particular mortgage, since the complexity of the slicing and dicing and passing on of responsibility had reached such heights. In some of these cases the courts have held that the person(s) in the home need not pay until such proof is furnished, cf., page 40.

Consider just one complication. Since the phenotype (and hence presumably the genotype) of a GE organism resulting for the insertion of some gene can depend on *where* the gene ends up, and the lab techniques cannot control[13] this geometry, there is a different organism for each geometric configuration. Since the resulting organism is a geometrically dependent synergy between a long previously existing system and the inserted gene(s), none of which were invented but found in Nature, by the way; it is not clear that anyone can at this time even define rigorously what exactly the resulting GE organism is, let

[13]According to a Dec. 18, 2009, news article, "As Patent Ends, a Seed's Use Will Survive," by Andrew Pollack, *The New York Times*, as the patent expires on Roundup Ready^{TM} soy, "Monsanto said it was confident that most farmers and seed companies would move to Roundup Ready 2, which uses the same bacterial gene but places it in a different location in the soybean DNA . . . ." Much of the information about this technology is a trade secret; however, it remains to be seen just how carefully the location of an inserted gene can be controlled. Even if we assume that the geometric location can be specified exactly, *all* of the effects of this genetic modification are difficult (impossible?) to predict, and can only be learned after the fact by extensive research.

alone patent it.[14] Of course, hundreds of billions of dollars depend on these patents, thus any related lobbying of law makers or litigation in the courts would be intense!

A Short, Incomplete List of Potential Problems with GE.

Food Safety Concerns. If one wants to do research on GE food one needs to be knowledgeable and funded – and, as of the decade prior to 2009, get the approval of the GE industry to publish if one gets their genetically engineered products from the GE industry, the only legal source, cf., page 114. There is the famous case of the research of Dr. Arpad Pusztai, on GE potatoes, conducted at the Rowett Research Institute in Aberdeen, Scotland – ending in 1998. You can read the details in [488, 643, 644], and in [587], where author Andy Rowell is an investigative journalist who was closest to the "action" in the U.K. The one line summary is: eminently qualified researcher, Dr. Pusztai, with a long and distinguished career conducts research on GE potatoes, finds evidence that they may be dangerous to the public health, is so alarmed that he says so in a public forum, and is immediately terminated. (The DVD "The World According to Monsanto," has an interview with Dr. Pusztai.) I refer you to the three references just mentioned, to [9, 313, 386, 497] and others, that address, in part, the issues of potential health problems of GE food.

Genetic Pollution. Then there is the case of Dr. Ignacio Chapela, University of California, Berkeley, whose research in 2001, published in *Nature*, showed that GM corn had contaminated important sources of native corn in several rather remote areas of Mexico, viz., 15 of 22 areas in Oaxaca and Ixtlán. Thus he established that genetic contamination, or pollution, was occuring and remains a problem for those, such as organic farmers, who wish to remain GE free, and anyone with an interest in maintaining the genetic seed banks of "original corn" intact and uncontaminated. Dr. Ignacio also opposed a large corporate tie-up between U.C. Berkeley and a large multinational biotech company, Novartis (later Syngenta). There followed a remarkably nasty public relations campaign against Dr. Ignacio and his research. He survived, but the campaign managed to divert attention from the fact, now confirmed by other researchers, that the genetic contamination Dr. Ignacio discovered was real, cf., [488, p. 235] and [587].

Freedom to Farm GE Free. If you farm you may want to remain GE free so that you can save your seeds from year to year, a practice going back thousands of years; genetic contamination is a real threat which might lead to legal prob-

[14] After some investigation it appears unclear to me whether or not the courts would accept this argument. I have noted, however, that on March 29, 2010 *The New York Times* reported that United States District Court Judge Robert W. Sweet issued a decision invalidating seven patents related to genes whose mutations are associated with breast cancer, BFCA1 an BFCA2. The judge argued that the patents were "improperly granted" because they involved a "law of nature." How have appeals courts, businesses, and congress reacted to this decision?

lems. Consider the case of Percy Schmeiser (http://www.percyschmeiser.com/, wikipedia, and www.monsanto.com), a farmer specializing in the breeding and growing of canola in Bruno, Saskatchewan, Canada for over 40 years. If you buy GE seed from Monsanto you need to sign a 'Technology Use Agreement' stating that you will not save seed, that you will allow Monsanto detectives to come on your property at any time for purposes of enforcing this agreement. Schmeiser did not buy seed from Monsanto and did not sign such an agreement. Nevertheless, Schmeiser has stated; Monsanto detectives trespassed on his land, gathered seeds that were found to be Roundup Ready^{TM} canola, and sued him, for example, for a $37 per hectare fee for the use of such seeds. Schmeiser claimed genetic contamination. Most farmers give up when confronted with a multimillion dollar legal team. He did not. Read about his ongoing efforts on the Web. Monsanto has a view that differs from Percy's, available at their website. The Center for Food Safety, CFS, has views different from Monsanto's. For example, they have done a preliminary report on the number of farmers that have been sued by Monsanto, the amount of money awarded Monsanto by the courts, and its effect on agriculture. How many farmers have been sued by Monsanto, anyway? See www.percyschmeiser.com/MonsantovsFarmerReport1.13.05.pdf for the CFS report, "Monsanto versus U.S. Farmers."

Pest Resistance. With near mathematical certainty long term, frequent use of a given pesticide results in the evolution of pests that are resistant to that pesticide, be it glyphosate or *Bt*. Use of herbicides gives rise to so-called "super weeds." For example, glyphosate-resistant weeds have been on the rise since GE crops started gaining momentum; and these weeds now total 15 species – up from 2 in the 1990s – that cover hundreds of thousands of hectares in the United States alone [426, p. 19].

Resistance to *Bt* poses major problems for organic farmers who now can spray the bacteria and infect pests, who then die when the bacteria infects its host and produces its signature toxin. Every cell of genetically engineered *Bt* corn produces this same toxin at many times the level found in the organic application. This hastens the appearance of resistant pests, and presents a plant residue every cell of which contains the *Bt* toxin. Since such biopesticides come from soil bacteria, and such bacteria likely have a natural function in pest control, there is a concern that some natural balances may be upset, permanently, cf., [313, p. 108]. You might want to check the Web, e.g., YouTube, for claims of some farmers that their pigs have suffered ill effects from eating *Bt* corn. (Note that Monsanto is apparantly seeking to patent certain pig lines as I write.)

Monocultures and Stability and Loss of Diversity. There is concern that GE crops are not stable from one generation to the next, and GE has certainly contributed to the rise of monocultures over enormous total areas. Independent farmers who have over millenia selected a diverse collection of food plants adapted to local conditions are being replaced by monocultures. Their knowledge and their plants have been largely lost as they disappear. Classical methods of plant (and animal) breeding and selection differ from GE in several ways. Species barriers are preserved, and *whole organisms in context are selected*. This makes it possible to select for complex traits such as "yield," where it may not yet be possible to isolate the precise genetic mechanisms (and other possible mechanisms, such as actors in the environment) that affect yield.

Control. Ever larger portions of our food supply are coming under the control of corporations who do not appear open to dialog with folks who disagree with their designs. Unfortunately even independent scientific investigators are not fully free to investigate the situation and communicate their findings to the rest of us.

The "Computer Code" of Life. I have heard in person scientists who discovered the human genome refer to that project as "reading the computer code of life." Anyone who has written a computer program of any complexity knows that if you make changes to a complicated program there will be bugs, i.e., unintended consequences. From experience then, we should anticipate unintended consequences if we start manipulating the genome of various organisms – and then introduce massive numbers of these organisms in the environment, while preventing independent scientific investigation of the products.

Exercise 5.8 Playing With the Building Blocks of Life. Several references in this book deal with potential problems with genetically engineered life forms, [386, 587, 643, 569]. Are they generally ignored?

(i) A common misconception is that humans have been doing genetic engineering for centuries via plant and animal breeding. How is genetic engineering decidedly different from the classic breeding of animals and plants, selecting for certain traits deemed desirable? (Note: Usually a rat cannot mate with a corn plant. Via genetic engineering rat genetic material can and has now been introduced into corn plants. Thus consider the role of species in ecosystems.)

(ii) It has been estimated that at least 60% of packaged food in the supermarket contains genetically engineered ingredients. Make your own estimate of this percentage at the time you read this.

(iii) How much choice do you have in whether or not you eat genetically engineered food?

(iv) Life is perhaps the most complex phenomenon in Nature. What does the Principle of Unintended Consequences say about genetic engineering of life forms? Does this Principle argue against humans doing anything?

(v) On the April 21, 2008 edition of www.democracynow.org we have: "In other food news, a new study by the University of Kansas has found that genetic modification reduces the productivity of crops. *The Independent* of London reports the study undermines repeated claims that a switch to the controversial technology is needed to solve the growing world food crisis. Researchers found that genetically modified soya produces about ten percent less food than its conventional equivalent." Did this story appear in, say, *The New York Times*? Examine major news media in the U.S., including National Public Radio, for any bias for GE.

Patterns of Inheritance and Mathematics. You no doubt have heard of Gregor Mendel who was an Augustinian monk who did experiments with heritable traits of peas in the 1860s. He discovered certain patterns were approximately followed as one went from one generation of peas to another. *A classical example.* There were some pea plants which when mated amongst themselves always produced tall offspring. These are referred to as "pure" or "true" breeding peas with respect to "tallness." Assign to such pea plants the label TT. (Why I do this will become apparent in a minute.) Likewise, there was a class of pea plants that when mated amongst themselves always produced short pea plants. Assign to these plants the symbol tt.

When Mendel bred "pure tall." i.e., TT, peas, with "pure short," i.e., tt, peas, he got all tall pea plants – no short plants and no "in between short and tall" plants. He thus called "tallness" a *dominant* trait, and "shortness" a *recessive* trait. The parent-plants in this experiment are referred to as the P (for parent) generation. The offspring of the above mating of two parents with a decided difference in the one trait, "tallness," is called the F_1 (first fillial) generation. After many trials Mendel observed that in the F_1 generation $\frac{1}{4}$ of the plants were "pure short," $\frac{1}{4}$ were "pure tall," and $\frac{1}{2}$ were tall, and did not breed true tall. But, again after many trials, on average if two plants from this last "half" were mated, $\frac{1}{4}$ were "pure short," $\frac{1}{4}$ were "pure tall," and $\frac{1}{2}$ behaved like the F_1 generation.

Mendel developed a simple mathematical "coin toss" model that was consistent with his results, i.e., provided an "explanation." Assume each pea plant has two genetic "particles," and there are three possiblities: TT, tt, and Tt. Assume that each parent contributes one "particle" to a given offspring. If a TT is mated with a TT, then each parent contributes a T, thus the offspring is again a TT. The same pattern holds if each parent is a tt. If one parent is a TT and the other is a tt, then each offspring (in the F_1 generation) must be a Tt, hence "tall" if T is the dominant "particle."

Now comes the interesting part. If two offspring in the F_1 generation are mated, what are the possibilities? Let's say we have two parents: "father," $T_f t_f$, and "mother," $T_m t_m$. What are the possibilities for the offspring now? Since father contributes "one particle," either T_f or t_f and mother contributes "one particle," either T_m or t_m, we have *four* possibilites: $T_f T_m$, $t_f T_m$, $T_f t_m$, $t_f t_m$. One-fourth will breed true tall, $\frac{1}{4}$ will breed true short, and $\frac{2}{4} = \frac{1}{2}$ will be tall but breed like the F_1 generation.

In the following exercise I will let you think about why this model gives the same result as "tossing a coin" twice, if T is heads and t is tails. Now it turns out that life is not always this simple. There are plants with traits where neither is dominant; matings give a blended result. A plant, the "four-o-clock," sometimes has white flowers, sometimes red. If a white and red are mated the offspring are pink, cf., [152, p. 266].

Independent, "coin toss," models apply if "particles," which we now call genes, are *independent*, viz., they are on different chromosomes and act as if other genes do not exist. We will look at such an example in part (viii) below. If two genes are on the same chromosome, they will tend to be inherited together and not act independently, cf., [152, p. 266].

Exercise 5.9 The Simplest Patterns of Inheritance

(i) Consider two coins with sides H (heads) and T (tails). If you toss one coin twice, what are the possible outcomes written as a pair of letters?

(ii) If you toss both coins at once, what are the possible outcomes written as a pair of letters?

(iii) Is your answer to (i) the same as your answer to (ii)?

(iv) In (i) is the first toss "independent" from the second toss? (Or are they linked in some way?)

(v) In (ii) is the outcome for each of the coins independent of the outcome of the other coin?

(vi) Compare your possible outcomes for either (i) or (ii) and compare them to the possible outcomes of mating two pea plants from the F_1 generation with each other. Are all of these three sets of outcomes basically "the same?"

(vii) Suppose p and q are two positive numbers that sum to 1, i.e., $p+q=1$. Suppose a gene has two alleles, A and a, with A dominant. Suppose that in a large population, where mating is random, that a fraction p of the population has allele A, and fraction q has allele a. See if you can that the fraction of the population that is AA is p^2, the fraction that is aa is q^2 and the fraction that is Aa is $2pq$. If $p=q=\frac{1}{2}$, you recover the F_2 generation discussed above with respect to "tallness." (Note the F_2 generation results from mating among the F_1 above.) The web-site http://www.k-state.edu/parasitology/biology198/answers1.html may be helpful. Note the binomial expansion: $(p+q)^2 = p^2 + 2pq + q^2$.

(viii) Suppose that c is the gene for cystic fibrosis. Assume everything is simple, i.e., you exhibit cystic fibrosis only if your genotype is cc. The "wild type," or normal allele, C, is dominant and if you are CC or Cc you do not exhibit the disease. Suppose that hair color is determined by a gene D for dark and dominant, d for fair and recessive. Assume that hair color genes and cystic fibrois genes are inherited independently. Suppose the genotype of "father" is: $C_f c_f D_f d_f$; and the genotype of "mother" is: $C_m c_m D_m d_m$. Thus both parents have dark hair and do not exhibit cystic fibrosis.

Since we are assuming independence of the disease and hair color there is equal chance that the father will contribute one of the four possibilities to his child: $C_f D_f$, $C_f d_f$, $c_f D_f$, $c_f d_f$. Replacing the subscript $_f$ with $_m$ we get the same for the mother. What are the chances that their child will exhibit cystic fibrosis and be fair? What are the chances that their child will exhibit cystic fibrosis and have dark hair? What are the chances that their child will exhibit cystic fibrosis? Can you answer this last of the three parts by ignoring hair color and looking at the example on "tall versus short peas" already worked out?

5.5 Toxic Sludge is Good for You!

A Major Design Flaw in Our Civilization. The flush toilet is a candidate for the single greatest thing that differentiates "modern living" from the "primitive." Before the industrial revolution and crowded cities, human waste invariably ended up in the soil, via outhouse or emptied bed pan, not far from where it originated. With cities eventually came the invention of flush toilets that moved human waste, using water for transport, to the nearest lake, ocean, river or stream to prevent the obvious health problems of letting "it" pile up within city limits. This, of course, resulted in water pollution – but it was out of sight of the city. In time this problem could have been solved with sewage treatment plants that removed human waste from water and returned that human waste to the soil – where it would have gone in the first place. But developing industry, a driving force for the formation of cities, also had its waste – a usually toxic brew.

The *great mistake* was to do the easiest thing, let industry dump its toxic waste into the same sewer system that carried human waste. Along with this came the common practice of citizens dumping all manner of unwanted waste into this sewer system as well. A *second great mistake*, made in hundreds of U.S. cities, was to combine rainwater runoff with sewage. One of the functions of rainwater is to recharge the groundwater; a job that is thwarted by lack of absorbant urban landscaping and insufficient use of porous paving materials. Thus "When it Rains it Pollutes" since many sewer systems cannot handle the volume of rainwater runoff that occurs when it rains. *"In the last three years alone, more than 9,400 of the nation's 25,000 sewage systems – including those in major cities – have reported violating the law by dumping untreated or partly treated human waste, chemicals and other hazardous materials into rivers and lakes and elsewhere, ..." "More than a third of all sewer systems – including those in San Diego, Houston, Phoenix, San Antonio, Philadelphia, San Jose and San Francisco – have violated environmental laws since 2006 ..." "As cities have grown rapidly across the nation, many have neglected infrastructure projects and paved over green spaces that once absorbed rainwater. That has contributed to sewage backups into more than 400,000 basements and spills into thousands of streets, ... Sometimes, waste has overflowed just upstream from drinking water intake points or near public beaches."*[15] In all of the industrialized countries, populations grew to the point where the sewage from the city upstream was no longer "out of sight" of the city downstream. In the United States the tipping point came in 1972 with the passage of the Clean Water Act. Sewage treatment plants were built to "clean up the water" before it was discharged to its next user. Since the purpose of the treatment plant is to remove as much pollution from the water as practicable, what remains is pollution – a mixture of human waste, household waste, and toxic industrial waste – toxic sludge.

The problem then becomes: what does a city do with its toxic sludge? To be honest, I had not thought much about this until I read *Toxic Sludge is Good for You!*, cf., [560]. This book is primarily about how the Public Relations Industry, (PR), manipulates our society; but Chapter 8 deals specifically with toxic sludge. This book provides a wealth of details on how the EPA, various corporations and municipalities participated in a public relations campaign to rename *toxic sludge* as *beneficial biosolids*. There are five methods for dealing with toxic sludge; one of which, ocean dumping, has been banned. The method of gasification (using sludge to make methanol or energy) is most environmentally sound, but the most expensive, according to EPA *whistleblower*, Hugh Kaufman,[16] The EPA opted for the least expensive method,

[15]Quotes are from: "Sewers at Capacity, Waste Poisons Waterways," by Charles Duhigg, p. A1, *The New York Times*, Nov. 23, 2009. Data originates with the EPA and state officials.

[16]A whistleblower is one who speaks truth *to* power about the powerful as opposed to a

encouraging toxic sludge to be spread on farm fields.

The farms around the small Colorado town of Holly (population less than 2000) received 25 tons of New York City sludge per day for a couple of years until a citizen "revolt" stopped it. Over the objections of local residents, farms around the impoverished Texas town of Sierra Blanca (population about 500) on the Mexican border were chosen as the final resting place of New York City toxic sludge. Hugh Kaufman was sued for going on the record with the following comments, cf., [560, p. 118], (he then countersued): *"This hazardous material is not allowed to be disposed of or used for beneficial use in the state of New York, and it's not allowed to be disposed of or used for beneficial use in Texas either. What you have is an illegal 'haul and dump' operation masquerading as an environmentally beneficial project, and it's only a masquerade. . . . The people of Texas are being poisoned."*

More recently in 2002 we read:[17] *"Earlier this year, Synagro, the nation's largest sludge producer, paid a Greenland, New Hampshire family an undisclosed amount of money to settle a wrongful death suit - the first payment to an alleged victim of sludge induced sickness."*

Box-flow models can be applied here. Large boxes containing water are "the oceans," "the atmosphere," "ground water." Candidates for subboxes are the watersheds of any group, e.g., city, a collection of people; a collection of animals or people; a collection of industrial facilities, etc. Candidates for flows are flows of water and pollution. With such boxes and flows in mind a little thought leads to at least one conclusion: overall the intervals of time between the moment water leaves a pesticide plant, a cow or a toilet until the moment someone drinks it are growing shorter and shorter, cf., Exercises 20.1.

A similar analysis works if you subsitute the word air for water. As we shall see in Chapter 7, the supplies of water, especially fresh water, and the envelope of air that sustains us minute by minute – these supplies are far smaller, thinner more vulnerable to human impact than at first you might be able to imagine. How urgently you might be concerned right now about the sentiments above depends on quantitative details: Just how long is that interval of time between toilet and water fountain, car exhaust to lungs? The

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snitch who informs the powerful about the powerless. Hugh Kaufman blew the whistle on toxic contamination at Love Canal, and Times Beach (Missouri), and is known for his fearless honesty. He had to withstand enormous pressures to maintain his integrity. He blew the whistle on EPA administrator, Christie Todd Whitman, just after the attacks on the World Trade Center in 2001: "*There's enough evidence to demonstrate that Mrs. Whitman's statement to the brave rescue workers and the people who live there [in lower Manhattan] was false."* Kaufman is referring to Whitman's statement of Sept. 18, 2001: *"I am glad to reassure the people of New York ...that their air is safe to breathe and their water is safe to drink."* See [238, p. 4]. Some of those brave rescuers have already paid with their lives, many with their health.

[17] http://www.organicconsumers.org/Toxic/sewadge_sludge.cfm. The website of the Organic Consumers Association, and the Environmental Working Group, www.ewg.org are two sources for current information on toxic sludge/biosolids from the point of view of organic consumers/farmers, respectively, environmentalists.

sufficiently motivated can take the mathematics of the following exercise far beyond what is required for this book.

Exercise 5.10 We All Live Downstream

(i) Would a ban on placing nonbiodegradable waste in the sewer system help make toxic sludge less toxic? Can you think of a system for handling all nonbiodegradable waste other than putting it in sewers?

(ii) Research the *composting toilet*. Estimate the number of flush toilets in some area you are familiar with that could be converted to composting toilets – which require no water, and produce compost for soil. Estimate the amount of water saved per year if such conversions took place. What are the minimal energy requirements of a composting toilet?

(iii) What are some of the *pathogens* in toxic sludge? Why are they a problem in sewage sludge? Are they a problem in soil?

(iv) Consider your last drink of water. Estimate the interval of time that had elapsed since it was flushed down a toilet or sent out as a discharge from an industrial facility? Note that bottled water is quite often just processed tap water – even some "famous" brands. Pick a couple brands of bottled water and research until you find the sources of that water.

(v) Confirm, debunk or refine the conclusion that in today's world the more people there are the shorter is the time between the moment water is one person's effluent to the moment it is a source for someone else.

(vi) Is the following statement true? "Nearly half the people in the world don't have the kind of clean water and sanitation services that were available two thousand years ago to the citizens of ancient Rome."[18]

(vii) Compare the intervals of time from (iv) with the half-lives of pollutants. For example, how much time lapses between the moment water runs off an agricultural field (or a lawn) sprayed with your favorite biocide (or water soluble fertilizer) and the moment someone else drinks it? Compare this with the estimated half-life of the biocide. Note that the half-life of a substance is the length of time for half of a given quantity of a substance to "decay" or change into something else (also possibly toxic). Half-life of a toxic chemical can depend on environmental conditions. Half-life, as it refers to radioactive decay of a substance, is a physical invariant of that substance.

(viii) Investigate the prevalence of *endocrine disruptors* in your drinking water, food supply and in sewage effluent, both upstream and downstream from you. For a research project investigate the prevalance (they are everywhere), effective dosages (sometimes in parts per trillion), and effects (there are very, very many) of endocrine mimics and/or disruptors. I predict that if you do this project you will probably be surprised at your exposure, the possible effects – to the point you might get upset.

(ix) Pick a river and estimate the interval of time from the moment a bit of water is flushed down a toilet, or discharged from an industry, in city A until the moment it is taken from the river downstream as drinking water by city B.

(x) Estimate the amount of energy per liter city A, in (ix), expends processing its sewage, and the amount of energy city B expends processing drinking water (so that the water meets EPA standards, both as a sewage discharge and as drinking water.) Where does this energy come from?

(xi) From the point of view of physics and mathematics, air is a fluid, just as is water – only less dense and viscous. Repeat (iv), (v), (vii) with air substituted for water. Note

[18]This quote is from "The Last Drop: Confronting the possibility of a global catastrophe," by Michael Specter, *The New Yorker*, October 23, 2006, pp. 60–1. The United Nations Development Program issued a report in November of 2006, cf., *The New York Times*, Nov. 10, 2006, titled "Beyond Poverty: Power, Poverty and the Global Water Crisis," Kevin Watkins, the lead author. About 2.6 billion people have no access to a "bathroom," and more than a billion people drink, wash in, and cook with water contaminated with human and animal feces.

that many pollutants may start out as liquids or solids but that they become airborne as vapors or small particles.

(xii) Can you document particles of dust and/or pollution traveling in the atmosphere from Asia to the U.S.? From Africa? Can you document any type of pollution traveling in the atmosphere from the U.S. to the Arctic or northern Canada? From the U.S. to another continent?

(xiii) Which fertilizers sold for home gardening contain toxic sludge?

(xiv) Starting say with the article by Katherine Tweed, "Sewage's Cash Crop," *Scientific American*, November 2009, p. 28, investigate the process described there where slow-release phosphorus fertilizer pellets are processed from Portland, Oregon's sewage by Durham Advance Wastewater Treatment Facility. What is the toxic content of these pellets, if any? Could such a process be applied to animal waste, e.g., sewage lagoons on industrial pig farms? Do humans eventually have to figure out a way to recycle phosphorus, a key ingredient in plant growth? To what extent does removing phosphorus diminish "dead zones" and algal blooms? Note that a key word associated with the above process is *struvite*.

Exercise 5.11 Two Boxes of Water: Oceans and Atmosphere

(i) Estimate the residence time of water in the box, the earth's atmosphere. Note: From [283] (a 1988 book) there is $1.3(10^{13})\ m^3$ of water in the atmosphere, and the global precipitation rate is $5.18(10^{14})\ m^3/yr$. Do you think these figures have changed due to global warming? Note that [91, pp. 20-2] gives precipitation on salt water to be $4.58(10^{14})\ m^3/yr$ and precipitation on land to be $1.19(10^{14})\ m^3/yr$.

(ii) Estimate the residence time of water in the earth's oceans. Note: In [283, p. 26–7] the exercise is done for you. However, all you need is the amount of water in the oceans, which is $1350(10^{15})\ m^3$ (in 1988), and the global precipitation rate, cf., section 3.3. Any global warming changes? Note that [91, p. 20] gives $1351(10^{15}\ m^3$ for global salt water volume.

(iii) A very important topic which we have no room to deal with here is the present and looming shortage of clean, fresh water for much of the world's population. Given the stresses of population growth and pollution will water sources that are now managed by public utilities be privatized as were the trolleys? See [631, 33, 296, 693, 639, 698, 98, 586, 337].

(iv) There is another topic, quite important to a complete model, or any study, of pollution. Even with the strictest of laws intended to protect the public health, which we have not yet achieved by the way, there is the matter of enforcing those laws. Investigate the role of *organized crime* in the disposal of toxic and/or hazardous waste, cf., the next few paragraphs. With regard to Sierra Blanca mentioned above, Hugh Kaufman further endeared himself to many with the following quote: *"We're talking about government basically taking a dive for organized crime during an open criminal investigation."* See [560, p. 119].

Hazardous Industrial Waste in Your Garden or Farm Fertilizer? Toxic waste from sewage sludge is one thing, but can hazardous industrial waste be deliberately added to farm and garden fertilizers (as a cheap method of disposal, for example) – legally? From [727, p. 165], *"If some of the chemicals in a toxic waste can be used as a plant food, the toxic chemicals go along for the ride."* Thus the solution to pollution is dilution. This shocking state of affairs came to my attention through a series of newspaper articles[19] first pointed out to

[19] Thursday, July 3, 1997, "Fear in the fields: Part 1: How hazardous wastes become fertilizer." Friday, July 4, 1997, "Fear in the fields: Part 2: How hazardous wastes become fertilizer." Friday, July 4, 1997, "Throughout the country, example after example of hazardous wastes being turned into fertilizer." Friday, July 4, 1997, "Tag-along toxics." Thursday, July 3, 1997, "From factories to fields." Friday, July 4, 1997, "Two approaches to

me by Adrienne Anderson.[20] These articles were written by investigative reporter Duff Wilson who later wrote the book *Fateful Harvest*, [727], about the subject.

You might be as surprised as I was to learn that substances deemed unsafe in our air and water – lead, cadmium, other heavy metals, radioactive products, assorted poisons, and so on – can be legally considered safe to spread as fertilizer on the soil of our farms and home gardens. Might a possible source of some of the toxic substances found in our blood, cf., Chapter 4, be the "recycling" of hazardous waste as farm (home garden) fertilizer? This practice is thought to be expanding, yet I have not found anyone who claims to have the "big picture" telling us just how much hazardous waste is being applied to our farms and to what effect. Among the enablers of this situation are large corporations, government agencies, unsuspecting farmers and others, cf., [727].

Duff Wilson's exposé would not have been written were it not for the courageous whistleblowing of Patty Martin, the mayor of a small Washington (state) town, Quincy. She was led to discover this method of toxic waste dumping by failed crops, sick animals and rare diseases in and around her town. For her efforts she was almost run out of town.

The author of [717], Eileen Welsome, wrote a series of articles[21] about the "plutonium in your pancakes project" of then Environmental Studies instructor, Adrienne Anderson, wherein plutonium was shown to be one of the likely pollutants in certain fertilizers.[22]

Exercise 5.12 Fertilize Your Food with Hazardous Waste and/or Toxic Sludge.
(i) Investigate the contribution of toxic fertilizer to the stock of toxins in your body. Relevant references include [730, 727].

toxins in fertilizer." (The Canadian and American ways.) Thursday, July 3, 1997, "Heavy Metals in Fertilizers." July 3, 1997, "Here's what's known, and not known, about toxics, plants and soil." July 4, 1997, "Experts: How to reduce risk." July 3, 1997, "Resources on the World Wide Web." These articles were available on *The Seattle Times* web site, and other places on the web, at the time of writing.

[20] An instructor in Environmental Studies at the University of Colorado who was "let go" and her classes cancelled in 2005, against her wishes and over student protests. After fully investigating the case, the university's Faculty Privilege and Tenure Committee unanimously ruled that the university's academic freedom rules and her rights had been violated and called for her reinstatement. The university's administration refused to do so. She and her classes investigated the polluting practices of some of the world's largest corporations. She once won a $450,000 judgment (regarding a pollution case) which was reversed by the 10^{th} Circuit.

[21] "Dirty Secrets," *Westword*, April 12, 2001, Vol. 24, No. 33; "A Matter of Trust," April 19, 2001; and "Board Games," April 26, 2001. *Westword* is a weekly newspaper published in Denver, Colorado.

[22] If allowing toxics into fertilizers strikes you as "an experiment on the people," actual medical experiments on unsuspecting populations are not as rare as they should be. Besides the famous experiments of Nazi doctors in World War II, see: the plutonium experiments in [717]; as well as syphilis experiments in [573] (and Susan Reverby's work on experiments in Guatamala); and [318], for starters.

(ii) As of 2004 there were about 9,700 approved agricultural toxins. If you tested each of these individually there would be at least 9,700 tests (maybe more if other variables than the number of toxins are taken into account). I once had a conversation with a pharmacist who told me that if a person interacts with a number of chemicals, the order in which one interacts with those chemicals can be important to the outcome. If order is taken into account, what is the least number of tests needed if pairs of (different) toxins were tested for interaction/synergistic effects?[23]

(iii) Do you think the tests discussed in part (ii) have been done? How long would it take?

(iv) One-half of one millionth of one gram, i.e., .5 μg, of plutonium, Pu, is considered an amount sufficient to cause cancer in a human. How big is this amount? Note that Pu has a density of $\frac{19.8\ g}{cm^3}$, cf., [284]

(v) Explain why pollutants which persist for long periods, i.e., they have long half-lives, tend to be found throughout the biosphere. List all of the mechanisms for the transport of pollutants that you can think of.

(vi) Research César Chávez and Dolores Huerta. What does their work have to do with toxins in the U.S. food supply – with civil and human rights in general?

5.6 Media Concentration

Essential information, this is food for the mind. I will deal in more detail with the global flow of information in VIII. In 1983 ownership of the *media*, i.e., TV, radio, other electronic media, music, newspapers, magazines, movies, books, journals, was distributed over 50 corporations. By 2004 more than half of all media was in the hands of 6 or fewer corporations, cf., [20]. I call this collection of media corporations, with some intelocking agreements/boards, the *megamedia.* It is a common assumption that if something happens that we need to know about, the megamedia will tell us in a timely fashion. I wish to challenge this assumption throughout this book. For example, there are some important, easily understood things in this book that many of my students see/learn for the first time – which they should have learned in elementary or secondary school. This is evidence for my thesis that: *The range of debate in the megamedia is so narrow that much important information does not reach sufficiently many people in a timely*[24] *fashion – resulting in the unnecessary perpetuation of problems.*

Exercise 5.13 The Megamedia

[23] What are the number of permutations of 9,700 things taken 2 at a time? See IV. The same question for three (pairwise different) toxins at a time. The same question for four (pairwise different) toxins at a time, and so on. How many tests are there (at a minimum) if you add all these answers up, from 1, 2, 3, 4, 5, . . . , (all the way up to) 9,700 toxins at a time?

[24] For example, if you get correct information after it is too late to do anything about it, you did not get that information in a timely fashion.

(i) What are the 5 or 6 corporations making up the megamedia at the time you read this? What is(are) your source(s) for this information? See VIII.

(ii) Give evidence either for or against my thesis that the megamedia range of debate is too narrow.

(iii) How many people actually have ultimate control over the information that is carried by the megamedia? For example, is there any example of information that all of these people did not want to disseminate and it was not disseminated – at least in a timely manner?

(iv) Give evidence for or against the proposition that the megamedia is deferential to power. Make a list for and against, and assign weights to each example of their relative importance to society.

(v) Is there any important information that the megamedia did not convey to the general public in a timely fashion in the recent past? Did anyone gain financially because of it?

5.7 Oceans: Rising Acidity and Disappearing Life

One of the first lectures I attended as a new faculty member decades ago was on *"CO_2 Emissions and the Mean pH of the World's Oceans,"* by the late Dr. Roger Gallet of NOAA. The picture he painted was something akin to a science fiction horror film, except that it was science nonfiction. Briefly, the story goes like this. As humans burn fossil fuels, on average about a tonne of C, carbon, in the form of CO_2, carbon dioxide, is put into the air per person per year.[25] More CO_2 in the air means more CO_2 dissolves into the oceans. Everyone, know it or not, is familiar with the result: carbonated water – the way soda pop is made by forcing CO_2 gas under pressure into water. The more CO_2 in the air, the greater the (partial) air pressure of CO_2 on the world's ocean water, the greater the amount of CO_2 goes into the oceans. Chemists tell us that when CO_2 goes into water, carbonic acid, i.e., H_2CO_3, is formed, i.e., we get "fizzy water."[26]

Now the more H_2CO_3 the more acidic, i.e., the less alkaline, is the ocean. Dr. Gallet put up several scenarios on the board: 10% of the CO_2 emitted goes into the oceans, 25%, on up to 50%, the worst case scenario he considered. By the way, pH is a measure of how acid (or alkaline, the opposite of acid) something is.[27] A pH of 7 is neutral, neither acid or alkaline. The pH of pristine seawater is 8 to 8.3, slightly alkaline.[28]

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[25] This is an average, with some people putting in a lot more, some a lot less. These days the average is a bit more than a tonne per person.

[26] Well, not entirely. The pressure used to make soda water, i.e., fizzy water, is higher than the atmospheric pressure of CO_2.

[27] The pH is measured on a logarithmic scale, like the Richter scale for earthquakes, cf., section V. If the pH goes down one unit, say from 6 to 5, acidity increases by a factor of 10. If pH increases by one unit, say from 8 to 9, then acidity decreases, i.e., alkalinity increases, by a factor of 10.

[28] The pH of common substances are: milk (6.5), acid rain (5 or less), coffee (5), beer (4.5),

So what does this mean for life in the world's oceans? There are at the base of the food chain very small organisms that happen to need calcium compounds in order to build their tiny bodies.[29] The bones in many whales and other marine mammals as well as the bones in fish contain calcium which can only get there if these larger organisms have these smaller organisms to eat directly or indirectly. These smaller organisms need to extract and hold onto calcium from the ocean, and this becomes difficult to impossible if the ocean is not sufficiently alkaline. The little bodies' calcium parts essentially dissolve if the pH is too low. Most of the familiar life forms in the oceans, including coral reefs, cease to exist. This was the picture Dr. Gallet laid out in his lecture long ago. Possible death of the oceans as we know it, if the pH gets too low.

So what do we know now? The best science available, as reported[30] in [146], tells us that *"The ocean has absorbed fully half of all the fossil carbon released to the atmosphere since the beginning of the Industrial Revolution."* This was Dr. Gallet's worst case scenario. Currently about one-third of *current* CO_2 emissions are going into the oceans. (Incidentally, as a smaller percentage of our carbon emissions go into the oceans in the future, if we continue with business as usual, the CO_2 in the atmosphere will increase even faster than it has in the recent past, accelerating global warming.) Thus roughly 40% of CO_2 emissions stay in the atmosphere, 30% are taken up by vegetation on land and about 30% goes into the oceans. The resulting overall drop in the pH of surface waters is about 0.1, which may not seem like a lot; but ecologically it is a relatively large change. A change in pH of 1 means a change in acidity by a factor of $10 = 10^1$. We will see that a change in pH of .1 means a change in acidity by a factor of $10^{.1} \approx 1.2589$, or a change of about 26%. If we go with a fossil fuel century, the pH will drop an additional 0.3 by 2001, and $10^{.3} \approx 2$. Predictions of ocean pH several centuries from now show a pH lower than at any time in the past 300 million years.

As the pH of the ocean decreases entire oceanic systems shift. Coral reefs, half of which were dead or dying in 2009, could literally all dissolve if the pH gets too low. Thus as Gallet warned, everything with a calcium carbonate shell/skeleton is vulnerable: oysters, clams, snails, many sponges, sea urchins,

orange juice (3.5), cola (2.5), lemon juice (2.4), stomach acid (1.5–2.0), battery acid (.5), blood (7.34–7.35), hand soap (9–10), household ammonia (11.5), bleach (12.5), lye (13.5).

[29]For example, a type of phytoplankton called coccolithophorids, which are covered with small plates of calcium carbonate and which float near the ocean's surface doing photosynthesis. Another, planktonic organisms called foraminifera, related to amoeba. Another, small marine snails called pteropods.

[30]This *Scientfic American* article, [146], is one of very few popular articles (see also the article of Kolbert, footnote [31] on the next page) I have seen dealing with the acidification of the world's oceans. Read this article for a deeper, more detailed description of what is going on than I have room for here. This problem is not well known to the public! Coupling global acidification together with other pollution and overfishing, cf., footnote [7], Chapter 7, it appears that sea life is at extreme risk.

and on and on, including many of the aforementioned planktonic organisms at the base of the the food chain. All the fish and sea mammals that have calcium in their bones will have to find another way to get that calcium if that calcium does not enter at the base of the food chain as it does now; and it is not clear that such a pathway exists. But maybe the "worst" will not happen. I really do not know how the base of the food chain in the oceans will shift as the pH goes lower, or how the planet will respond as we continue to emit CO_2 in vast quantities. As the planet warms maybe there will be a rather rapid release of methane, cf., the PETM exercise below. (Why would this be an important event?) Mathematically speaking one thing is clear: we are dealing with an extremely complicated non-linear system with a multitude of synergistic interactions – and we are giving this system a strong "kick." Non-linear systems often respond unpredictably when perturbed! Indeed, some experts fear dire consequences if we go with business as usual regarding the burning of fossil fuels.[31] It appears that a smart goal for humanity would be zero net carbon emissions as soon as possible, but I see little indication that humanity is at all close to even discussing this possibility.

One question that has occurred to me to ask is this: What effect will this acidification of the world's oceans have on oxygen production? As you know, quite a bit of the world's oxygen is produced by photosynthetic activity in the ocean. For example, it was discovered in 1986(!) that the "blue-green" bacteria, *Prochlorococus*, the most numerous life form on the planet with 10^{27} individuals, contributes about 20% of the oxygen in the atmosphere, cf., [161, p. 54]. Thus the O_2 in every fifth breath you take is thanks to the *Prochlorococus*. Other ocean photosynthsizers contribute an additional 50% of atmospheric oxygen. From the "box-flow" point of view there are three "boxes" that contain most of the oxygen atoms/molecules: the earth's crust and mantle contains most, 99.5%, an estimated $2.9(10^{20})$ kgs of O_2; the biosphere, 0.01%, an estimated $1.6(10^{16})$ kgs O_2; and the atmosphere, .36%, an estimated $1.4(10^{18})$ kgs O_2, cf., http://en.wikipedia.org/wiki/Oxygen_cycle. The residence times of O_2 in each of these boxes is, respectively, 500,000,000 years (crust and mantle); 50 years (biosphere); 4,500 years (atmosphere). About $3(10^{14})$ kgs O_2 flow between the biosphere and the atmosphere each year. Only $6(10^{11})$ kgs per year flow in/out of the earth's crust/mantle. How will this system change as global warming proceeds and the oceans become more acidic? I have not found any definitive predictions as to what will happen. However, the article on global phytoplankton decline, [54], does not make me optimistic. For example, the oceans phytoplankton account for approximately half of the production of organic matter on Earth, as well as about half of Earth's atmospheric oxygen. This article estimates oceanic phytoplankton biomass as a function of time since 1899. The author's estimate a global rate

[31] The popular article, *The Darkening Sea: What Carbon Emissions are Doing to the Ocean*, by Elizabeth Kolbert, in the November 26, 2006 issue of *The New Yorker*, pp. 66–75. See also [359] and [161].

of decline of about 1% of the global median per year, with an approximate 40 % decline in phytoplankton biomass since 1950. Critics of [54] believe that increasing CO_2 in the atmosphere, and increasing nutrient runoff from lands into seas will increase phytoplankton biomass.

There are three possibilities: the new situation will produce more, the same, or less oxygen. Of course, less oxygen would be troubling. (Just how are those phytoplankton going to react, anyway; will any other organisms fill in for them if they fall by the wayside?)

If there is more oxygen something very interesting might happen. About 300 million years ago, during the Paleozoic Era, insects were much larger. Dragonflies had wingspans of 2.5 feet! It so happens the time of large insects coincided with a time when oxygen content of the atmosphere was 35%; it is 21% today. It has been proposed that the only factor preventing insects of today reaching relatively gigantic proportions is the oxygen content of the air.[32]

In summary so far, we are initiating changes in the earth's biosphere, including the oceans, rather quickly; and "recovery" of the system more to humans' liking may take hundreds, thousands, or hundreds of thousands of years – if such "recovery" is possible at all.

Exercise 5.14 Rising Ocean Acidity, Acid Rain, pH, and Menhaden Fish

(i) If going from a pH of 8 to 7 means multiplying acidity by a factor of 10, then going from a pH of 8 to 7.9 means multiplying acidity by what factor?[33]

(ii) Consider this quote: "Scientists measure acidity by the 'pH' scale familiar to every high school chemistry student. Since 1800, ice core measures show the ocean's average pH level has dropped from 8.2 to 8.1, making it 30% more corrosive, Feely says. Expected emissions will likely drop it to a pH of 7.9 this century, a 150% increase in acidity since 1800, he says." (Quote from : http://www.usatoday.com/tech/science/2006-07-05-ocean-acidity_x.htm, which is a news article about a study, "Impacts of Ocean Acidification on Coral Reefs and Other Marine Calcifiers: A Guide for Future Research," co-authored by Richard Feely of the NOAA Pacific Marine Environmental Laboratory in Seattle.) Do you understand this statement, and is it correct?

(iii) The effects of CO_2 on the world's oceans will likely not be uniform. Investigate the variablity of this phenomenon.

(iv) How much of the biosphere's oxygen flow is generated by photosynthesis in the oceans? How does this compare with the oxygen flow generated by the green plants on land?

(v) One of the causes of acid rain is sulfur dioxide, i.e., SO_2, emissions from coal-fired power plants. If you want to begin a study of how such emissions affect the pH of rain water see [283, pp. 120–3].

It has been reported that the largest source of mercury pollution in the United States is the burning of fossil fuels. You can make a project out of examining all known toxic

[32] This theory was proposed in research done by scientists from Midwestern University, Arizona State University and Argonne National Laboratory presented in October, 2006, at meeting of the American Physiological Society. They arrived at this conclusion by studying the way oxygen is transported into and around an insect's body, via spirales and tracheae. In today's situation, for example, the largest a beetle can grow and properly oxygenate is 15 cm.

[33] If you cannot do this problem now, try it again after you have studied V.

emissions of coal-fired power plants and examples of effects in specific cases, e.g., molybdenumosis. There are many reasons besides global climate change for switching from fossil fuels. Is there a body of water near you that is contaminated by mercury from burning coal to make electricity?

(vi) Investigate a previous episode of global warming that occurred 55 million years ago, the Paleocene-Eocene Thermal Maximum (PETM). Was the biodiversity of the oceans affected? Did the system recover? How long did it take and under what circumstances? For example, see http://currents.ucsc.edu/04-05/06-13/ocean.asp, a newspaper article about a research paper that appeared the week of June 13, 2005 in *Science*, by James Zachos, et al.

(vii) What is the status of the Menhaden fisheries at the time you read this. Menhaden have been called the most important fish in the sea. Why? See [204].

Oceans: Two Common Patterns of Destruction. There is a common *pattern* of exploitation of a resource that will surprise no one. Humans take the most valuable, easily available part of a resource first. We saw this in Chapter 1 with regard to oil. (This pheonemon is related to the concept of *entropy*, cf., VII. Resources with the lowest entropy, i.e., most order or value, are taken first.) We have seen it with regard to trees, where the biggest are gone first. Ore deposits that are the richest (and accessible with the technology available) are gone first. For example, an ounce of virtually pure gold could be found 150 to 200 years ago in many a gold nugget in the creek beds of Colorado or California; today over 400 tons of ore are mined and processed to get that one ounce of gold.

Thus it has been with the resources in the ocean. According to [161] 90% of the big fish/mammals in the oceans are gone today, i.e., the populations of large beings have been *decimated*, i.e., reduced to one-tenth. Among these are the several species of whales, many species hanging on after having been driven almost to extinction. Various varieties of dolphins, porpoises, seals, walruses, sea otters, manatees, dugongs, polar bears and on and on, all mercilessly expoited, most decimated or driven to extinction. "Modern humans" have been working on this project for hundreds of years, all chronicled in [547, pp. 151–4] or [161], or for the "new world" by Farley Mowat in the classic *Sea of Slaughter*. Cape Cod was aptly named because of a resource which today is gone from Cape Cod. The 500-year-old Canadian cod fishery collapsed in the 1990s. John Steinbeck wrote *Cannery Row*, about a sardine industry that pulled 600,000 tonnes of sardines a year off the California coast in the 1930s; today gone. This last example is interesting in that small fish can become a large resource when they travel in enormous schools. And we rarely stop short of, at least economic, extinction. Example: the magnificent Atlantic Bluefin tuna, close to biological extinction, still has price on its head – in the 1990s one 200 pounder could fetch $100,000, cf., [161, p. 65].

And we don't even eat all that is caught. I was not really familiar with the term "by-catch" until one of my students, who had worked for an extended time on a fishing boat in the Bering Sea, a "botton dragger" or trawler, wrote a paper on it. Scraping the bed of the sea, destroying immeasurable amounts of life in the process, hauling up the catch and then throwing away an immense portion in a deceased state because it is not the desired, or legally allowed, form of life – is routine. The official global estimate of by-catch is 8%, and for shrimp trawlers the official figure is 62%, said to be an underestimate by some. Longliners with thousands of hooks on central fishing lines of up to 100 kilometers (60 miles) are estimated to kill some 4.4 million sharks, sea turtles, seabirds, billfish, and marine mammals in the Pacific each year.[34] Even more sadly, nets, many-mile long lines with hooks, and lobster traps are often lost at sea and continue "ghost fishing," killing untold amounts of wildlife for unknown lengths of time, cf., [161, p. 61].

After peaking in the year 2000 at 96 million tons, the wild fish catch fell to 90 million tons in 2003, then rose to 92 million tons in 2006, but see the following exercise. Though the total catch may seem stable, we are "fishing down the food chain," in that as more popular species become rare, substitute species are turned to. Even the remaining "large" fish are getting smaller as the older (sometimes 50, 100 and even 200 year old!) fish are fished out. For example, in the 1950s the average blue shark weighed 52 kgs, in the 1990s 22 kgs, cf., footnote [34]. Aquaculture is growing rapidly (from 1 million tons in 1950 to 40 million tons in 2003 and growing by more than 3 million tons annually), but it is not without complications. Increasingly, wild fish are rendered into fish meal for carnivorous farmed fish, and sometimes wild habitats are essentially destroyed in the process of farming fish. Note that farmed salmon consistently have significantly higher levels of dioxin than their wild counterparts, cf., [426, p. 22].

I will say no more here except that if we continue what we are doing the science is clear. In [735] an in depth analysis was done of the probable consequences of our current relationship to life in the sea. The conclusion simply put is that species have been disappearing from ocean ecosystems at an accelerating rate. If continued, by 2048 *all* fish and seafood species will have been decimated – officially collapsed, cf. also Chapter 7. We will have extended decimation from the large all the way down the food chain. We can avoid this fate by using the $15 to $30 billion spent per year (in current national government subsidies for the fishing industry) to instead do two things: (1) create "new job training" for unsubsidized fishers; and (2) create (by expanding upon the existing global marine sanctuary system) a global network of marine reserves protecting up to 30 percent of the worlds oceans which would cost around $13 billion, cf., footnote [34]. If we do nothing but continue business as usual we will be left with algae to cultivate as the last "sea food." Nature will indeed have shown forbearance if we successfully rescue this last algal remant, because of our second deadly common pattern.

The *second common pattern* is our propensity to take the easiest way out in disposing of what we consider garbage. Nature knows not the concept of waste; every being's effluent is a resource for another form of life – except for synthetic products not previously known in Nature which are not biodegrad-

[34] http://www.earth-policy.org/index.php?/indicators/C55/

able, e.g., plastics. If you have never heard of the immense floating islands of human-made debris in our oceans you should do a little research, cf., [161, 92–107]. One of the largest is the Great Pacific Garbage Patch, estimated to be twice the size of Texas, in the northeastern part of the Pacific gyre, with a counterpart in the western portion. Plastic kills wildlife. Plastic mistaken for food clogs digestive tracts and kills.

Add to this some additional toxic waste: nuclear waste, chemical waste, farm and urban effluent and on and on. The oceans are not as immense as we might like to think, cf., Chapter 7. Of course, the planet and the oceans will go on, but they may go on without us as a survival adaptation! There has been an overall trend for hundreds of years, from forests to fish. In anti-Bio-Copernican fashion "modern man" has taken for himself, to the point of exhaustion, all things within reach; and what we are finding out is that there is less and less left to support our lives.

Exercise 5.15 Living Resources in the Oceans

(i) Does the term "resource," when referring to wild, living beings, indicate an implicit assumption about the relationship of humans to these beings in the grand web of life?

(ii) How many "garbage patches" in the oceans of the world can you find? (For example, Kara Lavendar, lead investigator of a two-decade long study by Woods Hole, Massachusetts-based Sea Education Association, found considerable plastic garbage off the Atlantic coast of the U.S.A.) How big are each of them? How are they geographically distributed? What effect does garbage, lost nets, lost traps and other lost fishing gear, and toxic chemicals have on the wildlife in the oceans?

(iii) It has been asserted the official statements of global fish catches, such as stated above, are vast underestimates – in some ecosystems the real catch is double the official figure. This is due to the fact that recreational and "small" fishers are not reported, cf., http://ipsnews.net/news.asp?idnews=43118, and www.seaaroundus.org. How well do we know the actual fish catch each year? Are there any mathematical techniques that could be used to take into account, at least partially, the concerns expressed? Complicating even the official fishing industry stats is the following quote from, cf., footnote [34]: "Note: Taking into account probable overreporting by China, the worlds largest fisher, as well as climate-related fluctuations in the large catch of Peruvian anchoveta, the global wild catch has actually been falling for longer than the official records reveal – dropping 660,000 tons per year since 1988. For more information see Reg Watson and Daniel Pauly, 'Systematic Distortions in World Fisheries Catch Trends,' Nature, vol. 414 (29 November 2001), pp. 534–36." Discuss.

(iv) For a project, which requires a wee bit of calculus, investigate the concepts of Maximum Sustainable Yield (MSY) and Optimal Sustainable Yield (OSY) and how they are (and should be) used. For example, it is one thing to take the MSY as a *limit* which should not be exceeded under any circumstances, and quite another to take it as a *goal* to be achieved annually. A good place to start is with [90] which deals thoroughly with the mathematics involved. To what extent does taking whole ecosystems into account, rather than looking at each species individually, affect the mathematics?

(v) What is the Sea Shepherd Conservation Society, www.seashepherd.org? What has been their role in the world's oceanic ecosystems?

(vi) How many kilograms of fish (official estimates anyway) were caught per person in the world in 2000? In 2003? In 2006?

5.8 Stocks, Flows and Distributions of Food

A reasonably complete accounting of the stocks and flows of all food on the planet is a daunting exercise worthy of a book of its own. However, globally we have come to rely principally on three grains, i.e., cereal grasses: corn, wheat, rice, (which account for 85% of global grain production by weight) and marginally on others such as barley, sorghum, millet, oats, quinoa, amaranth etc. (Soy, an important food source, is a legume, hence in a separate category. It actually competes with grains for crop area.) Studying data on these grains is a solid measure of the world's food supply, since humans have gotten roughly half of their calories from grains for the last 40 years. The task of accumulating into a reliable three page summary the essential information (for the interval 1960–2007) on grains, globally, has fortunately been done, cf., [426, pp. 12–14]. From the box-flow point of view, if the matter in "the box" is the *global stock of all grains*, then the "flow in" is *global grain production* and the "flow out" is *global grain consumption*. A useful number to know each year is the *global grain production per person*.

Let's first look at the "flow in." In 1961 world grain production was $285\ kilograms/person * 3.069 * (10^9) persons = 874.38 * (10^9)\ kilograms$. In 1986 a peak per person production of 376 *kilograms* was reached, thus total production was $376\ kilograms/person * 4.918 * (10^9)\ persons = 1849.2 * (10^9)\ kgs$. For the last two decades the growth in grain production has matched population growth, with roughly $350 * (10^9)\ kgs/person$. So total world production has gone from approximately $350 * 5.267 * (10^9)\ kgs = 1843.45 * (10^9)\ kgs$ to $350 * 6.614 * (10^9)\ kgs = 2315 * (10^9)\ kgs$, (actually $2316 * (10^9)\ kgs$). After several years of declining harvest, 2007 was an all time record harvest.

One might think then that total stock of grain at the end of 2007 would also be high. Unfortunately, demand was so high that grain stocks fell to their lowest level in 30 years, namely $318 * (10^6)$ (*metric*) *tons*. This might seem like a lot, but it is only 14% of annual consumption, or about 51 days' worth. World grain stocks generally tended upward from 1960 reaching a peak in the mid 1980s of a little less than $600 * (10^6)$ (*metric*) *tons*, dipping for a while, regaining about the same peak in the late 1990s, and since then there has been a more or less steady decline. Contributing to this is the growing share, up to 17% in 2007, used to make biofuels like ethanol, cf., [426].

Consider some of the following details. In 2002, the world grain harvest of 1,807 million tons[35] fell short of world grain consumption by 100 million tons, or 5 percent. This shortfall, the largest on record, marked the third consecutive year of grain deficits, dropping stocks to the lowest level in a

[35] Note that reference [661, p. 23] gives $1.850(10^9)$ tons of grain production in 2002. Is this a significant difference?

generation, [58, page 7].[36] In 2003 grain production was less than consumption again. In 2004 global grain production was $2.015(10^9)$ tons, breaking the 2 billion ton mark for the first time in history, and exceeding consumption for the first time in 5 years. World cereal stocks, however, continued their long-term decline, standing at about 80 days worth of consumption in 2004, cf. [661, pp. 22-3].

Thus given all the above, it seems that there just might be limits on the amount of food we can grow, especially given the fact that most of our spectacular gains thus far depend heavily on fossil fuels.

Exercise 5.16 Grain Stocks and Flows and Population Growth

(i) What was responsible for the large growth in the global, monoculture grain harvests from 1961 to 2007?

(ii) How many kilograms are in a metric ton? Express as a power of 10.

(iii) Is the box containing the "global stock of grain" in steady state?

(iv) Approximately what percentage of land used for primary crop production in 2007 was devoted to genetically engineered grains, cf., page 115?

Distribution of Food: What are Necessary and Sufficient Conditions for Eliminating World Hunger? At the beginning of the 21^{st} century there is (was) clearly enough food to feed all humans on Earth, *if* it were approximately uniformly distributed. (Uniform distribution of food means each person would get an equal share of what food there is.) This can be considered proven if one accepts the data in [673], viz., that just half of the food currently being *thrown away* in the United States could feed the world's approximately 1 billion hungry people. As if to confirm this there is a growing movement of "dumpster divers," or *freegans*, who live off the discards of American supermarkets, restaurants and so on. In particular, freegan Daniel Suelo, who lives in a cave an hour's walk from Moab, Utah, has abstained from all forms of money, including barter, for 10 years, cf., "A Simple Life," by Jason Blevins, *The Denver Post*, November 22, 2009, p. 1A.

But even as food production and stocks rose to unprecedented levels a decade ago at the end of the 20^{th} century, malnutrition spread more widely than at perhaps any time in history. The World Health Organization (WHO) estimated in 2000 that fully half of the human family, some 3 billion people, suffered from malnutrition of one form or another, [211, pp. 6-7].

Consistent with these facts is the argument put forward by, for example, Nobel Laureate and economist Amartya Sen, that poverty, rather than food shortages, is frequently the underlying cause of hunger. Walden Bello, in

[36] Note that on July 6, 2004 the British Broadcasting Corporation's (BBC) science program interviewed Ken Cassman, of the University of Nebraska, and the International Rice Research Institute, Phillipines. Reporting on research results released that week Cassman stated that a 1 degree (Celsius) rise in nighttime temperature resulted in a 10% decrease in rice yields. Lester Brown, [58], notes that eroding soils, deteriorating rangelands, collapsing fisheries, falling water tables, and rising temperatures are converging to make it more difficult to expand food production fast enough to keep up with demand.

Food Wars, [36], analyzes the root causes for the spike in prices of basic food commodities from 2006 to 2008, putting the cost of essential foodstuffs out of reach for vast numbers of people worldwide – with accompanying social unrest.

The industrial agriculture model is not working for billions of people; and if we continue along the present path *it will not be safe and it will not be pleasant to live in a world where a majority of people have nothing left to lose.* Abstractly, to the central decision makers (my term), food for people, feed for animals, and food into biofuels are interchangeable investment opportunities. Satisfying people's need for food first is not a priority of the economic model. Thus speculation on food futures – as a commodity, shifting food to the biofuels sector, and so on, all helped make food unaffordable for billions. When your income is one or two dollars a day, there is not much room to maneuver. Policies of "structural readjustment" enforced by the World Bank and International Monetary Fund (IMF) plus trade rules of the WTO weakened various nations' ability to grow subsistence food for internal consumption. Thus people around the world are desperate for an alternative, for "*food sovereignty.*" Bello suggests that that alternative might be the Via Campesino movement, which is a marriage of numerous small independently managed farms with judicious input from science attending to local food needs first.

If the global financial system implodes fully, as it came near to doing in 2008, cf., Chapter 2, as the fossil fueled industrial ag model "runs out of gas," we may all be looking for "an alternative," which I have indicated exists in this chapter.

Thus even in the presence of plenty, distribution for many reasons leaves many people hungry and malnourished. Imagine for a moment that by magic we could implement a distribution system that gives everyone in the world a sufficient diet year after year. If that problem were solved could we sit back and rest – mission accomplished?

How Many People Can the World Support? In *How Many People Can the Earth Support?*, [102], we find that the answer "depends." It depends on the aggregate ecological impact of the world population; the lower the impact per person the more people possible. If the current fossil fuel based system were sustainable I would guess, based on agricultural considerations thus far in this book, and consideration of human consumption of the Net Primary Productivity of plants (NPP) in Chapter 6, 10 billion is the max – since everybody needs to eat! But [74] argues persuasively that we already have more people than we can support if we do not have access to abundant fossil fuels.

At this point values and the level of understanding of where humans fit in Nature come into play. For example, over the long term Nature leaves no known niches that can support life, unoccupied by life. There are no "biovacuums." The antithesis of the BioCopernican Axiom, cf., section 3.2, is "I am the only life form that counts." A slightly weakened form: "Life forms do not count unless they are a lot like me." Thus, the western hemisphere, what was to become the U.S. in particular, was fully occupied with life in 1492; and we should know how that turned out, although it is not always part of the curriculum. Indigenous peoples and ecosystems all over the world historically have similar tales to tell upon encountering "modern man."

By many measures, humans already occupy over 90% of the "space" available for life on earth. We are in the midst of the 6^{th} great extinction of living species, this time at the hand of humans, cf., [388]. If "we" truly valued the diversity of life that remains on the planet, "we" would figure out a way to make room for it by controlling our numbers and our planetary impacts so that this diversity could survive. The problems Nature has put in the face of humanity are not all that subtle, and "we" just do not "get it"; we strive for more economic growth as "good" and refuse to build a modern culture around an approximately steady state economics. Unfortunately this leaves Nature the one "solution of last resort": *Death will be (is?) Nature's way of telling us to slow down!*

To avoid collapse we might study the examples of collapsed civilizations that have gone before, [547, 137, 677]. We might study examples of human societies that maintained stable populations, cf., [285], and did not suffer the simplistic "nasty, brutish, and short" experience. In [435] Kerala, India and western Europe are offered as examples of numerically stable populations. In [409] it is argued that connecting with non-human-centered Nature is essential for a balanced life. To avoid collapse I think we must acknowledge that there are limits imposed by Nature, [450], and avoid bumping up against them.

I will throw out the following for debate as a minimal list of candidates for necessary and sufficient conditions for a stable population with a steady-state economic system.

(1) *Universal education* that includes a deep understanding of just how we as a group and as individuals are sustained by our environment. Every stable indigenous population is intimately aware of the aspects of Nature that give life and where they as a people "fit in" to Nature. "Modern man" by use of technology, urban living, and specialization has managed to create a people that has no fundamental understanding or conscious connection with Nature or the processes that their lives ultimately depend upon. Some are so isolated that they are not even aware that Nature exists; and if aware, they consider not only Nature as expendable, but a multitude of people as disposable as well. Just in case it is not clear, universal includes women and men, girls and boys.

(2) *Universal health care* which includes adequate nutrition, freedom from hunger, disease and abject poverty to the extent that a deep sense of community can provide. Parents are more willing to "stop at one or two" if they are confident their children will outlive them and go on to belong to a just society, see (3).

(3) *Equal civil rights and equal justice for all.* Just in case it is not clear, this includes women. The system of justice must be real, a fundamental part of culture, and preceived to be fair by all.

(4) Evolve a culture of dispute resolution within society which *minimizes violence*, hopefully to zero. Settle disputes with competing societies with a minimum of violence.

Exercise 5.17 What is Your Model for Achieving a Stable World Population with a Steady State Economy?

(i) Are current rates of population growth a problem in some parts of the world? Which parts? Find an example of a society, likely indigenous, that was (is) numerically stable. How did (do) they manage this?

(ii) In [137, 547] it is argued that living beyond the capacity of available natural resources leads to collapse. In [677] this reason is discarded as too simplistic. Instead a more complicated lack of ability to technologically respond to challenges is part of the key to understanding the collapse of complex societies. What do you think is happening to your society?

(iii) Richard Louv, in [409] discusses the consequences of "Nature deficit disorder." Does your society exhibit the symptoms? Do Louv's arguments support the Bio-Copernican Axiom?

(iv) Is the United States a country with a stable population? Does the U.S. have a steady-state economy? See V.

(v) Discuss, debate, embellish, improve, expand, delete, study, or change the four conditions for a stable population with steady-state economy. Create a Bigger Picture in which we can solve the problems of population growth and an exponentially expanding economy.

5.9 My Definition of Food

I am not completely happy with the following definiton of food, because I can already see how a clever public relations person might contort it to include some substance in the definition which I do not consider food. More likely, I can see how such an ingenious individual could make the definiton look completely surreal and silly. It is probably impossible for me to define food so precisely that I would agree with whatever a marketer might do with it in the future. Michael Pollan's motto is: "Eat food, not too much, mostly plants." In his books he makes a clear distinction between "food" and "edible, foodlike substances." Perhaps I should leave it at that, but I am a mathematician and I must try to define it. Thus, my defintion of what I consider to be *real food.*

Definition of Food: Food is a living or part of a recently living being (minimally processed) that it is culturally permissible for me to eat.

For me "recently" means that the quality has not deteriorated, so freezing extends the notion of recently. Some nuts and grains store well for a while before going rancid, and so on. Minimally processed allows for cooking or freezing, possibly home canning, but that is about it. Of course, I live in the real world and sometimes find myself eating, as Pollan would say, "edible, foodlike substances" which are too highly processed, overpackaged and contain ingredients which I have never heard of and cannot pronounce. The reference to "culture" rules out cannibalism, at least for the time being.

Exercise 5.18 Your Definition of Food
(i) Come up with your own definition of food.
(ii) How much of what you eat satisfies my defintion of food? Your definition of food?
(iii) Why did I wait until now to introduce my definition of food?

5.10 Choices: Central versus Diverse Decision Making

Folks who do not care if their food is genetically engineered, irradiated, "fertilized" with toxic sludge, grown on poor soils, "factory-farmed," or doused with herbicides-insecticides-fungicides-rodenticides, etcetera, can skip this section. However, if you would rather avoid, or at least diminish your exposure to, one or more of the foregoing list, fortunately, there are options.[37] A couple ways are to grow your own food, or be a hunter-gatherer. These options are not available to all of us, the latter because people wildly outnumber the wild beings on the planet (and wild beings are here and there polluted even more than humans are). Surprisingly the former is not available even to some farmers – who are caught working more than full time in the industrial model in an attempt to keep ahead of financial debts. However, just about anybody can grow some of their own food, if only some herbs in a window box in an apartment, or vegetables on a roof top or in a vacant urban lot.

Co-operating at some level with others in growing at least some of your own food is another option; for some ideas see, for example, [495, 263]. One of these ideas is CSA, Community Supported Agriculture. In one model of CSA a local farm has subscribers who pay an initial fee and then get an agreed-upon number of boxes of food per week during the growing season. Usually the option of working on the farm in lieu of some or all fees is offered. Another option is to just get to know some local farmers (are there any left in your area?) at their farms or at a farmer's market, and buy food directly from them. All of the options discussed so far provide the eater with more information than is typically available about food being eaten. You can know what the growing conditions of the food you eat actually are.

Most of us will be buying food at a market, which could be a farmer's market. If it is not, then there is the option of buying organically certified food. Like the 40 hour work week, weekends off, abolition of child labor – the offical USDA, United States Department of Agriculture, definition of "organic" was obtained only after a hard fought battle. Now it is possible to define organic in such a way that almost no food qualifies; but at a minimum most "organic folks" do not want food that has been genetically engineered, irradiated, and

[37]More than one study correlating pesticide metabolites in children's urine with children's diet found that eating organic food reduced exposure to pesticides in food from an "uncertain" level to a "negligible" one, [206, pp. 2–3], [701].

fertilized with "sludge," for example, to be labeled "organic." The USDA's original proposed definition of "organic" showed the heavy influence of industrial agriculture; and, by February 1998, two months after the USDA's publication of this definition in the *Federal Register*, 4,000 comments had been submitted – an unusually high number for a USDA notice. The USDA postponed the comment deadline and scheduled public hearings, and within a month the number of comments was up to 15,000! For example, the Rocky Mountain Farmers Union, (not to be confused with the Farm Bureau) weighed in with a cogent analysis, since it speaks for many small farmers (organic or not). By the time of the deadline the USDA had 275,603 letters, mostly negative – the most it had ever received during any comment period in its history. In response, antibiotics, sludge, GE, and irradiation were eliminated from the definition of "organic."

Maintaining a rigorous definition of organic will likely be an ongoing battle; but if the meaning of the word is lost, access of the public to truly organic food will be lost as well. Definitions are very important (plus inspection and enforcement).

A "quasi-industrial" model of agriculture can participate in the production of organic food, as it is defined; and to a limited extent it has. There are relatively large operations which adhere to organic standards. There are also co-operatives consisting of groups of farmers who provide the inputs for large buyers. As oil and natural gas become more expensive, it will be interesting to see how our system of agriculture evolves in response. A perspective of organic agriculture is found in [206], including origins, priciples, and "business issues."

One thing more, would an agricultural system alternative to the industrial model be affordable? The Economic Research Service of the USDA [38] has statistics on the overall percentage of the retail price to the consumer of domestically produced food that goes to the farmer, from 1950 to 2006. In 1950 it was 41% ($\frac{18}{44}$), in 1951 it was 42% ($\frac{20.5}{49.2}$), in 1952 it was 40% ($\frac{20.4}{50.9}$). From this point on the farmer's share of the retail cost of food declines, almost monotonically. For example, in 1960 it is 33% ($\frac{22.3}{66.9}$), in 1970 it is 32% ($\frac{35.5}{110.6}$), in 1980 it is 31% ($\frac{81.7}{264.4}$), in 1990 it is 24% ($\frac{106.2}{449.8}$), from 2000 to 2006 it is 19% (except for 2004 when it was 20%), i.e., in 2000 we have 19% ($\frac{123.3}{661.1}$), and in 2006 we have 19% ($\frac{163.2}{880.7}$).

You can think of the numbers in parentheses as follows. In 1951, 42% $= .42 = (\frac{20.5}{49.2})$, and in 2006, 19% $= .19 = (\frac{163.2}{880.7})$, where the number in the denominator is price/expenditures in billions of dollars paid by consumer, and the number in the numerator (also on billions of dollars) is the amount paid to farmers. The difference is the amount taken by what I have been calling the *central decision makers*. This number in 1951 was $49.2 - 20.5 = 28.7$. In 2006 this number was $880.7 - 163.2 = 717.5$. Now the only parts of the agricultural equation that are absolutely essential are the growers and the eaters. In the

[38]http://www.ers.usda.gov/Data/FarmToConsumer/Data/marketingbilltable1.htm

middle are the buyers, sellers, supermarkets, restaurants and so on who all perform various tasks. But they have been taking a larger and larger share of the food dollar as time has passed. This difference between what farmers are paid and what consumers pay is called the *consumer-farmer price spread*. This number has gone from 28.7 billion dollars to 717.5 billion dollars, which represents a change of 58% to 81% of the consumer's food dollar going to the "middle men." (On rare occasion the some central decision makers are caught and found guilty in court of price fixing, bribery, cover-up, and more, cf., [400, 170].) So when you ask: "Can I afford organic?" think of doing a reverse squeeze on the middle men, to help you pay for your groceries. Not all middle men are going away, nor should they. But the bottom line today, is that you the consumer could save about 81% of your food dollar by dealing directly with farmers! This may not happen overnight, and there will always be some costs involved in getting consumers and farmers to connect – there will still be middle men for most of us – but there is plenty of room for reverse squeezing if times get tough.

Consider the following comments of an activist dairy farmer from Wisconsin, Jim Goodman, in the *Progressive Populist*, Dec. 1, 2009, Vol. 15, No. 21, page 6.

"Even in the toughest economic times, the corporate buyers and sellers profit while the farmers loose (sic)." ... "Agribusiness spends multi-millions on lobbyists. Their lobbying efforts are aimed at increasing their profits, not farmer income or benefits to the consumer. They lobby for more cheap raw imports, less labeling, less restrictions on pesticide use and weaker environmental standards."

Earlier in his article we read:

"... a recent study by the Lieberman Research Group showed that organic food sales account for only 3.5% of all food product sales in the US." ....“Conventional farm milk prices have dropped by nearly 50% over the past year. Dean Foods controls 80% of the fluid milk market in some states and 40% of the market in the US; their net profits more than doubled in the last year."

"Conventional hog farmers have experienced losses for two straight years. Tyson, the second largest food company in the US, controls 40% of the US meat market. They reported a profitable third quarter for every segment of their business, including pork."

"When the farm price for beef cattle dropped $0.08 per pound, consumers were paying $0.17 more per pound at the supermarket. Average retail beef processing margins across all companies, increased 13% over 2008."

"And guess what, none of that was caused by organic farmers."

"Corporate agribusiness has a problem with organic farmers because they haven't yet figured out a way to totally bleed them like they have convential farmers. But as surely as corporate agriculture is working its way into the organic market, we suffer from their growing control."

Exercise 5.19 Common Assumptions About Industrial Agriculture. Determine as best you can the truth value (between 1 and 0) of the following assumptions. I believe the majority of mainstream media sources state or imply that the truth value of these assumptions is closer to 1 than 0. See [348] for arguments that they are false. Briefly discuss how you arrived at your answers. When you are done you might want to think through what you would consider an ideal system (or systems) of providing food, for yourself, your family, your community, the world.

(i) Industrial agriculture will feed the world.
(ii) Industrial food is safe, healthy, and nutritious.
(iii) Industrial food is cheap.
(iv) Industrial agriculture is efficient.
(v) Industrial food offers more choices.
(vi) Industrial agriculture benefits the environment and wildlife.
(vii) Biotechnology (including genetic engeneering) will solve the problems of industrial agriculture.

Exercise 5.20 We Are the Center of the Universe Pattern of Behavior: WACU

(i) Do you detect any corporatate behavior in the Hour Glass Industrial Agricultural system that follows the WACU Pattern of behavior, cf., Exercise 4.7.

(ii) If you answered yes to (i), can you name any of the corporations exhibiting the WACU Pattern of Behavior? Feel free to research the current state of affairs when you read this.

(iii) The global food supply has largely been corporatized. Will water supplies around the world be corporatized as well? What would be the consequences? The book [33] raises some issues worth thinking about, such as: Who would make such decisions? What does the WTO have to do with it? and so on. We will deal more with the "public ownership" versus "private corporate ownership" discussion in VII.

(iv) Discuss the implications of corporate ownership of your genome? How about the air?

(v) Compare and contrast the government centralized control of agriculture in the former Soviet Union to corporate centralized control of agriculture in the United States and elsewhere as it exists at the time you read this. Make a list of similarities. Make a list of differences.

5.11 Correlations

Correlations. When he was 84 I had the good fortune of having lunch at a Berkeley, Calif., café with Professor Jerzy Neyman, one of the greatest statisticians of all time. As he smoked one cigarette after another I ventured to ask: "Decades ago didn't you create some of the foundational statistics used to link lung cancer with smoking?"[39] He replied that he indeed had done such work. Then, taking advantage of the fact that Jerzy Neyman was quite kind and polite I pointed to his lit cigarette and asked: "Don't you believe in that work?" He replied: "Of course, but that is statistics; I am a special case!"

[39]Richard Doll in the early 1950s is credited with being the first to establish this statistical link between smoking and lung cancer. Self-taught statistician, Lawrence Garfinkel, and his colleagues at the American Cancer Society also deserve mention for their pioneering work beginning in the 1950s. Garfinkel was an ardent anti-smoker.

Statistics Helps Us Find the Cause – But Cannot Prove It Alone. Much might now be noted: the intense addictiveness of nicotine, the variability of human nature, the fact that Jerzy Neyman probably would have lived 10 more years, not 3, if he had not smoked. But Professor Neyman's point was mathematically correct: Pure mathematical statistics never proves anything, especially about individual cases. What the math did show was that the more you smoke the greater are your chances of getting lung cancer.[40] One suspects causality, but to come closer to proving it you have to do more science and understand more deeply.

For example, statistical studies surely would show that rooster crowing strongly correlates with the sun rising. But from a purely mathematical point of view you don't know whether rooster crowing causes the sun to rise or vice versa – or neither. You need more information to conclude what causes what. For example, just because one class of events A correlates with another class of events B, a causal relation is not guaranteed. There may be a third class of events C, yet unobserved, that causes both A and B. Statistics cannot tell us everything we want to know, but it certainly is a most powerful tool in showing us where to look.

Thus, not long ago cell biologists documented that a single component of cigarette smoke, benzo[a]pyrene, causes genetic mutations in lung cells that are identical to those seen in the tumors of smokers with lung cancer. These mutations occur not only in the exact same gene, called p53, but in the exact same location within this particular gene, cf., [666, page xv]. Do we now have the proof that we seek? Scientists would say, not absolutely – but with high probability we've got it. Those with conflicts of interest can use this rigorous scientific position to confuse folks who do not do science into thinking that smoking is safer than it actually is. Once a smoking habit is established, however, rational thought is not dominant, since nicotine in some people is more addictive than heroin.

Correlation Coefficient. Given two classes of "events" or "variables" such as soda consumption and body weight, what would the statement "these two random variables are correlated with a *correlation coefficient* of +1" mean? Well, we are now dealing with a subject in statistics called *linear regression analysis*,[41] and it turns out that correlation coefficients are always numbers

[40] Lung cancer is just one of the diseases smokers have to look forward to. In the *Los Angeles Times*, October 23, 2006, by Susan Brink, there is a report of the Copenhagen City Heart Study which is ongoing, started in 1976. Therein it has been found that smokers have a 1 in four, i.e., 25% chance, of developing chronic obstructive pulmonary disease, such as bronchitis or emphysema. Smokers lose an average of 6 to 10 years of life span. The study was published in the online journal *Thorax*. Note that lung cancer can be caused by other environmental factors such as radon gas.

[41] Nonlinear regression analysis is also possible. One way to do this is to *transform* data that appears to not lie on any straight line into data that does, using a trick – like applying a logarithm function. We will do this in the chapter on population models. This technique is also useful in studying many natural phenomena, like earthquakes, cf. [613].

between +1 and −1.[42] A +1 would mean there is a perfect (linear) correlation. That means if you graph one variable with respect to another on a pair of co-ordinate axes, as you may have done in some mathematics class before, the graph would come out a straight line with all of the points of your experiment (studying the relationship between soda consumption and body weight) lying on this line.

Positive and Negative Correlations. In the actual experiment with these two variables the correlation coefficient was not +1, it was a bit less. However, the study revealed that for each additional soda consumed (per day) the risk of obesity increased 1.6 times, cf., [489, p. 200].[43]

What does a negative correlation coefficient mean? In our example above, if body weight were negatively correlated with soda consumption,[44]then the risk of obesity would have *decreased* 1.6 times for each additional soda consumed per day. The real experiment did not come out this way, however.

Positive correlations have been measured in many experiments and studies involving food. The correlation just mentioned is of interest since educational institutions have been promoting soda drinking via exclusive campus contracts.

Hours of TV watched correlates positively with obesity, it also correlates posititively with increased blood cholesterol levels. Soda consumption is positively correlated with tooth decay. Perhaps more surprising, adolescents who consume soft drinks display a risk of bone fractures three to fourfold higher than those who do not, cf., [489, p. 200]. Product purchases of TV watchers positively correlate with the number of ads for that product shown on TV.[45] Hours watched of commercial TV correlate positively with caloric intake.

There is a positive correlation between high female status and low fertility across 128 different countries, cf., [426, pp 84–5].

Exercise 5.21 Positive, Negative, and Zero Correlation

(i) If two variables have a correlation coefficient of 0, what do you think this means?

(ii) Can you give an example of pair of variables, not mentioned in the text, that have a positive correlation coefficient? Can you give an example of a pair of variables that have a negative correlation coefficient?

(iii) Can you give any health conditions that positively correlate with the "western diet?" For example, high meat consumption vs. colon cancer or heart disease; consumption of high

[42] If you want to read more, [237] is as gentle an introduction to the subject for the non-mathematician as I am aware of.

[43] The correlation was not a perfect +1, it rarely is. Thus the points of the experiment did not all lie perfectly on the line in question, but the points were very close to this line. How do you find this line? It turns out you can find the best line graph approximation to a collection of data points with little effort by using a computer. Given a bunch of points, just tell the computer to do a *linear regression analysis* to get the line which best fits the data points.

[44] Thus the correlation coefficient would have been −1, say, or a number like −.8 of −.901.

[45] Contrary to what some believe, advertising/propaganda does work. Otherwise, no one would spend money on ads.

fructose corn syrup vs. obesity; exposure to certain endocrine disruptors vs. obesity, do these positively correlate?

(iv) Can you find a chemical with the following property. Corporation X manufactures chemical C. Corporation X funds research on possible negative effects of chemical C. Such research funded by X never finds any negative effects. Similar research funded by non-corporate sources nearly always finds negative effects of chemical C. Discuss the notion of correlation as it relates to this situation.

(v) If you have access to a computer with a spreadsheet program, cf., V, you can easily start computing correlations, i.e., the *correlation coefficient*, between two variables represented by two sets of data. What you need to do is compute a *regression line*, a best linear fit to the set of points in a plane obtained by plotting one variable versus the other. Given such a data plot, called a scatter plot, the spreadsheet program will compute the best linear fit (the regression line) and the correlation coefficient for you. Intuitively the correlation coefficient measures how tightly the scatter plot fits the regression line. If all the points in the scatter plot sit on the regression line, then the coefficient is ± 1, i.e., 1 if both variables increase together, -1 if one decreases as the other increases. See http://illuminations.nctm.org/LessonDetail.aspx?ID=U135 by the National Council of Mathematics Teachers for lessons easy enough for grades 9 through 12 or above. Another source explaining correlations is [237].