Environmental Science *Systems and Solutions*

FOURTH EDITION

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Chapter 13

FOOD AND SOIL RESOURCES

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Introduction

- As part of the global biosphere, we are ultimately dependent on other living organisms for virtually all aspects of our lives.
- Modern industry and medical technology are dependent on plants and animals for important drugs and other substances.
- Our most direct dependence is for nutrition through agriculture.

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Food as a Biological Resource

- There are 1000's of edible plants and animals, but only a few supply almost all human needs.
  - About a dozen grasses, 3 root crops, twenty or so fruits and vegetables, six mammals, two fowl, and a few fish species
- Only 20 different species of plants supply 80% of the world's food supply.
- Three kinds of plants (maize or corn, wheat, and rice) constitute 65% of the world's food supply.
- Meat production is dominated by a few terrestrial species: poultry, sheep and goats, pigs, and cattle.
- Freshwater and ocean fisheries are also an important source of human food.

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Food as a Biological Resource

TABLE 13-1 Global Food Production in 2004

Food Source	Metric Tons per Year
Grain	2 billion
Meat	258 million
Wild fish	93 million
Aquaculture	40 million*

*Data for 2002.

Hunger and adequate nutrition

- Currently, at least 800 million people do not eat enough every day for a normal healthy life.
- A standard level for inadequate nutrition (malnutrition) is difficult to define
  - it's dependent on age, gender, and activity level.
  - The typical male requires 2,700 and the typical female requires 2,000 calories a day in addition to vitamins and minerals.
- This amount of calories and nutrition allow people to carry out productive work. Many people do not consume enough to live and work actively.
- Either too little or too much food can jeopardize human health and welfare. In U.S., Europe, etc. too much food is causing obesity and many health problems, lowering life expectancies.

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Feeding the World Today

- Agricultural land is being plowed under for development.
- If the entire world followed the American diet, less than half the current human population could be fed.
  - Typical American gets 25-30% of Calories from animal sources (meat/cheese), Latin Americans only 10%
- Careful management of the world's food supply (perfect distribution and only vegetarian diets) might just barely feed the current population (40% of food lost to spoilage/rats/pests or thown away as leftovers)
- Currently about 1.5 billion hectares cultivated (=> 1/4 hectare/person)
  - 1 square kilometer = 100 hectares (1 hectare = 10,000 square meters)
  - 1 hectare about 2.5 acres, 1 square mile = 260 hectares = 640 acres
- Total land available for cultivation? Estimates vary between 2 and 4 billion hectares (how fertile does soil have to be? include land under highways and buildings? Include national parks?)

Food for the Future

- **Maintaining animal product-based diets and providing adequate food for all will require more food (see next slide)**
- **A growing world population will require more food.**
- **If exponential increase in population continues, no way to feed everyone adequately**
- **World production could be increased though two basic strategies:**
  - **Increase the amount of land in cultivation**
  - **Increase the yield per unit of land under cultivation.**
- **Many projections ignore the detrimental and nonsustainable aspects of modern agriculture, so many lean toward low side**
  - **Land is being degraded, so even current yields will be hard to maintain**
  - **Some optimistic (cornucopians) estimate 50 billion people could be fed; assumptions going into these estimates are clearly wrong. However, in past yields have GREATLY increased, much more that Neo-Malthusians thought possible. With Genetic Modification (GM) foods, etc. will new large increases will be possible?**

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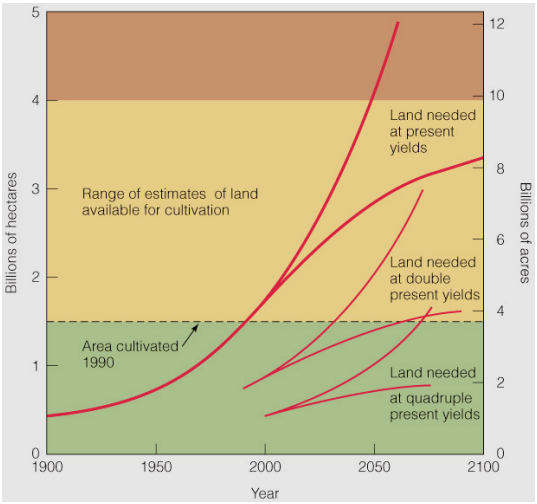
Figure 13-3 Possible Land Futures.



Source: Adapted and updated from Meadows DH, Meadows DL, Randers J. Beyond the Limits. Post Mills, VT: Chelsea Green, 1992, p. 51.

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Agricultural Food Production and Supplies

- **Grain is the major source of the world's food supply.**
- **It is used directly by people and to feed livestock.**
- **Total world grain production nearly tripled between 1950 and the 1990s due largely to the Green Revolution.**
- **Still, the world grain production per person is currently below its all-time high.**

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Agricultural Food Production and Supplies

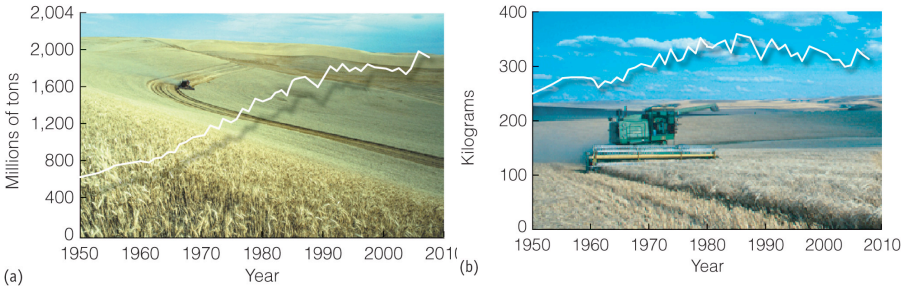

Figure 13-4 (a) World grain production, 1950-2005. (b) World grain production per person

(Source: USDA/FAS and U.S. Bureau of the Census.

World Grain Stocks

- Not all grain produced in a year is consumed that year.
- "Carryover" grain stocks are a measure of global food security.
- When stocks drop too low, grain prices fluctuate widely, making it more difficult for the poor to buy food.

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Land, Fertilizers, and Water is needed

- New land is put into cultivation each year but it is now being equaled by land removed from cultivation due to soil exhaustion, degradation, and the building of roads and structures. Currently more land added than removed, but that may change
  - In India, ground water is being pumped out so fast that water table is dropping more than 4 feet per year; North China plains water table dropping more than 7 feet per year
  - In Indonesia, more than 600,000 hectares (2300 square miles) rainforest cleared to grow soybeans for chicken feed
- Besides 1.5 billion hectares for cultivation, about 3.3 billion hectares used for animal grazing.
  - Not all of 1.5 billion used for food; some for cotton, opium, etc.
- Artificial irrigation used for about 0.28 billion hectares
  - Hard to increase this too much due to fresh water limitations

Land, Fertilizers, and Water Devoted to Agricultural Production

- **World grain production has increased in spite of per capita land losses (the world population continues to grow) through more intensive agriculture using:**
  - **Mechanisation**
  - **Special varieties of crops**
  - **Artificial fertilizer**
  - **Pesticides and herbicides**
  - **Irrigation**

Courtesy of Jeff Vanuga/USDA Natural Resources Conservation Service

Figure 13-8 Spraying pesticide on leaf lettuce in Yuma, Arizona.

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Effects of Agriculture

- **Most agricultural ecosystems are inherently unstable (pioneer stage) and require constant human attention.**
- **Pioneer stage effects include:**
  - **Highest bio-productivity**
    - More pounds of crop per acre per year than climax community
    - Also results in soil nutrient depletion (requiring fertilizers)
  - **Humans like monoculture (e.g. only corn; everything else is called a weed)**
- **Get much greater yields using irrigation, but effects include:**
  - **Salinization and waterlogging (and eventual destruction!) of soil**
    - Egypt irrigated sustainably for millenia, but recent changes mean 30% of land now suffering from salinization
    - Around 1 million hectares abandoned in China since 1980

(a)

Figure 13.06a: Pioneers cut down climax stage forests to build their homes, grow crops, and generally "tame" the wilderness.

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Effects of Agriculture (continued)

- **Besides desalinization and waterlogging other problems**
  - **nutrient depletion**
  - **topsoil loss**
  - **Toxics from herbicides, pesticides, fertilizers enter water supply, rivers, oceans, etc.**
- **Denuded soils quickly erode**
  - **In most undisturbed forest soil build up is faster than erosion**
  - **Soil forms at about 1 inch per 100-300 years in U.S., 1 inch per 2000 years in many places, but soil can be lost in just a few years of poor agricultural management**
  - **Rich U.S. corn belt soil may be mostly gone before middle of this century (Soil came from Canada during last ice age!)**

Is Destruction of Soil New?

- **Traditional agriculture, done by humans for millennia, coped with these effects several ways:**
  - **Slash and burn (swidden)**
    - Burning releases nutrients to soil
    - Plant for a few seasons then move on letting natural succession (pioneer to climax populations repair land)
    - Only possible when human population in area is small
  - **Fallowing (use fields only every other or every few years)**
  - **Crop rotation (e.g. plant legumes to fix nitrogen in soil)**
  - **Promoting diversity by intercropping**
    - E.g. Amazon aboriginals planted 70 different species cassava (tapioca) at same time, mimicking a climax community!
    - Central Americans interplant corn, beans, and squash

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What is Soil?

- **Without soil, we probably could not grow food**
- **Soil is comprised of weathered, disintegrated, decomposed rocks and minerals plus the decayed remains of plants and animals, plus air and water**
- **Soil supplies nutrients and holds water in place**
- **Healthy soil is a complex ecosystem unto itself.**
- **Soil is yet another resource, made by nature over thousands of years being rapidly used up by humans! Is it renewable or not? Depends on whether use is sustainable or not.**

The Soil of the Earth

- **Soil "horizons" have different attributes.**

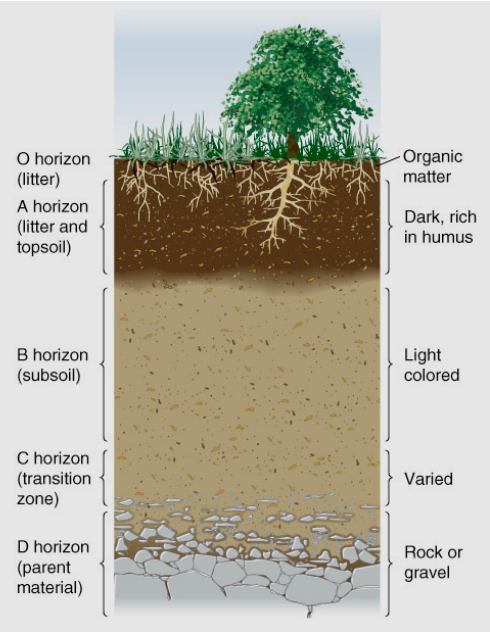

Figure 13-15 A typical soil is composed of five horizons.

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Erosion

- **Estimates indicate 25-75 billion metric tons of soil loss per year globally due to deforestation, livestock overgrazing, and agricultural activities**
- **In U.S. for each inch of topsoil lost, average corn and wheat yields drop about 6%.**

Figure 13-14 Topsoil loss in Palouse, Washington.

Courtesy of Tim McCabe/USDA Natural Resources Conservation Service

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Green Revolution

- **Modern agriculture utilizes high-yield crops and massive amounts of fertilizer, herbicides, and pesticides to raise yield per acre (hectare). Also intensive irrigation.**
- **This type of agricultural practice was begun in the 1960s by the United Nations in a massive campaign to increase yields.**
- **Mechanization takes large amounts of energy. In U.S. very few people (i.e. farmers) are involved. Oil and water are basically converted into food by agricultural machines. (about 16% of U.S. energy used for food; note how energy keeps popping up as an environmental lynchpin…)**

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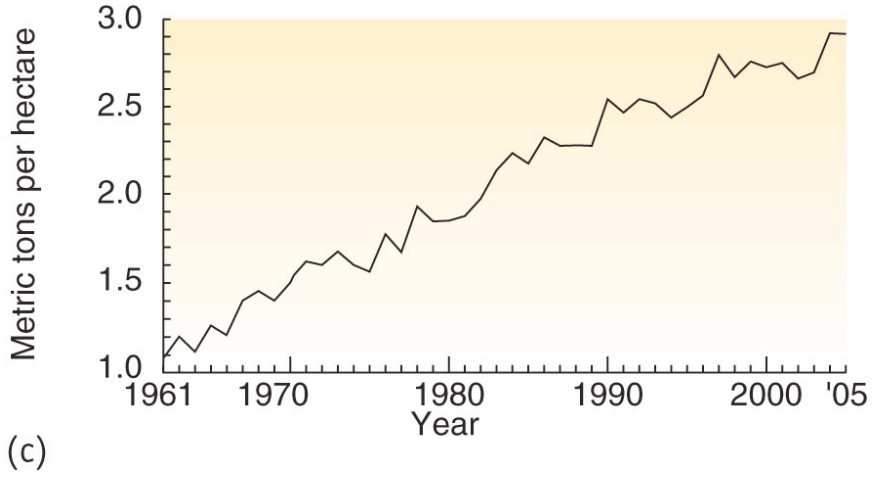

Figure 13.09c: World wheat yields, 1961-2005.

Source: United Nations Food and Agriculture Organization.

Grain Yields

- **The gains of the Green Revolution well into the late 1980s were impressive but it is not clear they can be continued.**
- **The techniques employed are not sustainable and soil fertility is declining in many parts of the world.**

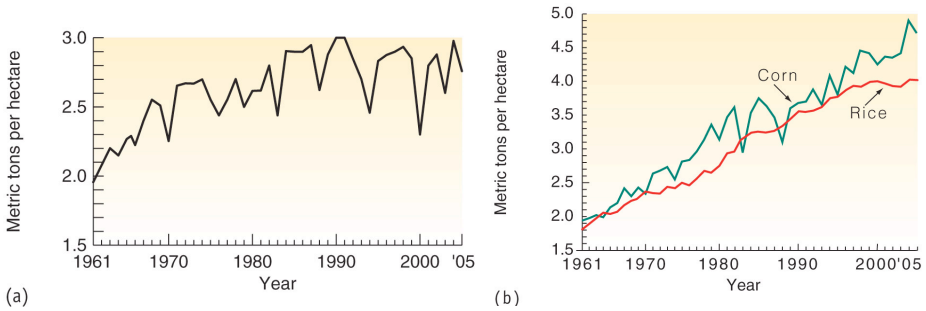

Figure 13-9 (a) World mixed grain yields, 1961-2005. b: World maize (corn) and paddy rice yields, 1961-2005.

Source: United Nations Food and Agriculture Organization.

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Green Revolution

- **The Green Revolution has lead to nutrient depletion of trace elements, and long-term damage to soil.**
- **Intensive irrigation has stressed fresh water supplies**

Figure 13-7 Salt-affected agricultural land near Katanning, Western Australia.

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Desertification

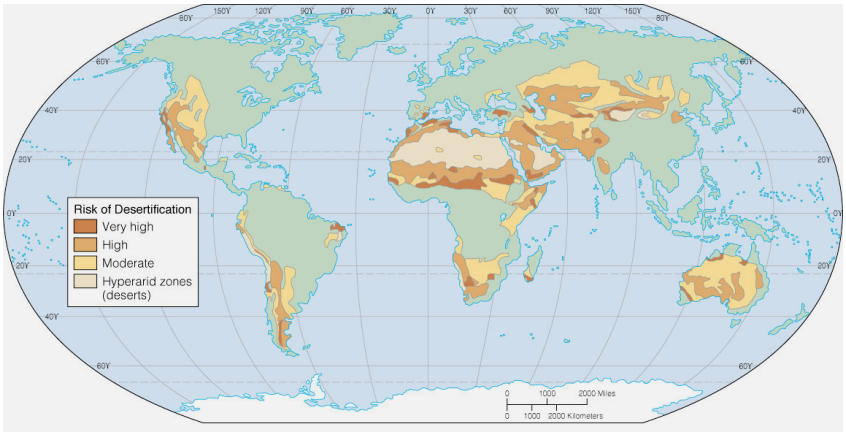

Figure 13-10 Deserts and areas at risk of desertification.

Source: Based on United Nations data.

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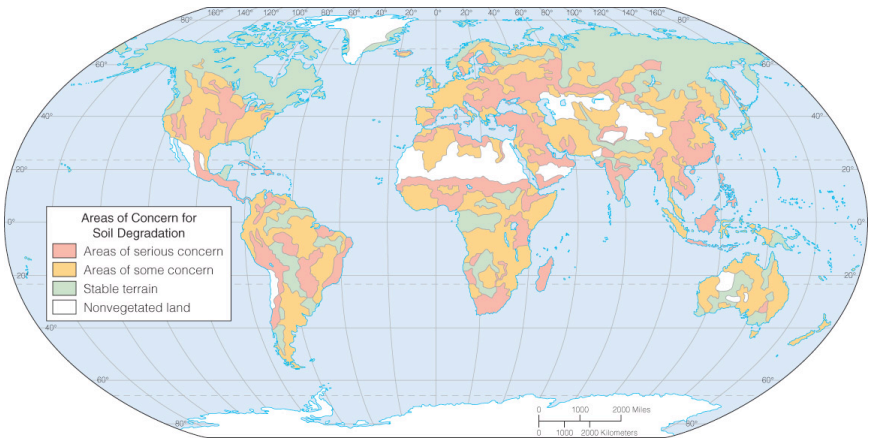

Figure 13.16: Areas of concern for soil degradation.

Source: Adapted from World Resources Institute. *World Resources 1992-1993*. [New York: Oxford University Press, 1992], p. 117.

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- **Most livestock grown in U.S. are raised in large-scale "concentrated animal feeding operations" (CAFOs)**
- **Up to a million animals held in a single facility**
- **High population densities have greatly increased yields, reduced time to market and increased profits (e.g. < 8 weeks between birth and chicken nuggets)**
- **High population density require heavy use of antibiotics and can cause severe local air and water pollution**
- **UCS: antibiotic resistant Staph bacteria (MSRA) evolution has been linked to massive antibiotic use in CAFOs**

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Beyond the Green Revolution (New ideas in Soil preservation)

- **Higher Yields through Sustainable Agriculture: Techniques such as:**
  - **no-till sowing of crops (seed drills)**
  - **drip irrigation (saves much water)**

Courtesy of Lynn Betts/USDA ARS

(a)

Courtesy of Gene Alexander/USDA Natural Resources Conservation Service

(b)

Figure 13-17 (a) No-till planting. (b) Drip irrigation delivers water directly to plants.

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Beyond the Green Revolution (continued)

- **Integrated pest management (IPM)**
  - Do not try to totally eliminate pests; just control them so no serious damage to crops
  - Use "natural" controls such as biological preditors, crop rotation, fallowing, interplanting, natural fertilizers (compost, animal manures, even human waste)
  - Yields and profits seem to be as good as regular commerical agriculture
  - Close to sustainable
- **Organic farming**
  - Takes IPM to the next level and says no synthetic chemicals: ferilizers, pesticides, or herbicides, or genetically modified varieties

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Figure 13.CS01_1: Ancient earth and stonework structure in the Peruvian Andes used to collect water during the wet season.

Photo by Robert Schoch, August 2005

Genetically Modified (GM) Crops

- New plant varieties created for millennia by cross-breeding within one species. New genetic techniques allow transgenic crops (aka GMO and "Frankenfoods")
- Can incorporate genes from other species, e.g. fish genes into strawberries (to stop them from freezing!)
- Most GMOs engineered for pest resistance or weed control
  - E.g. Bacillus thuringiensis (Bt), a bacterium makes toxins lethal to caterpillars/butterflies of the Lipidoptera family and Coleoptera (beetle family). These bacteria genes have been transferred to corn (to protect against cutworms) and potatoes (to fight potato beetles). Bt GMO varieties in some cases have allowed farmers to use 75% less pesticides.
  - Monsanto's "Roundup Ready" crop varieties include genes that give resistance to their pesticide Roundup (glyphosate). Farmers can spray fields heavily with this pesticide and all weeds will die, but crops grow fine.

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Genetically Modified Organisms (GMO) (continued)

- GMO use has grown exponentially
  - In 1996, 1.7 million hectares planted with GMOs worldwide
  - In 2005, over 80 million hectares now planted (numbers wrong?)
    - 25% of world's total cropland, U.S. accounts for over 60% of that
  - Main producers are U.S., Argentina, Canada, and China
  - In U.S. around 70% of all food contains some GM component
  - 30% of all corn, over 80% of soybeans, and over 70% of cotton in U.S. are GMOs.
  - Currently many European, African, and Asian nations do not allow Bt or various other GMOs
  - Currently GMO's and products containing GMO's are not labeled as such in the U.S., so you can't know whether or not you are buying/eating them (actually if you are eating in the U.S. you almost certainly are!)

GMO Issues

- **Higher crop yields may be possible (feed more people), but UCS says actual studies of yields don't confirm this on average in U.S.**
- **Less pesticides, soil damage, etc. may be possible (e.g. Bt cotton in China means much less pesticides and less environmental damage)**
- **Other properties could be engineered**
  - **better taste, grow on salty land, use less water, etc.**
  - **higher nutritional value (e.g. Golden rice that contains vitamin A; but amount of vit A is so small that it may not be worth it)**
  - **Longer shelf life, or better shipping properties (e.g. Flavr Savr tomato by Calgene/Monsanto)**
  - **Genetic engineering is still very young, so many, many other properties will become possible. Basically traditional plant cross-breeding is sped up by a huge factor and limits of what GM can do are not known.**
    - e.g. new varieties can be engineered so that e.g. corn plants produce pharmaceuticals and/or plastics

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GMO Issues (continued)

- **GM properties may spread by regular pollination to other crops or to other plants**
  - **If Bt gene spreads to other plants, then "super weeds" will exist that normal mechanisms (i.e. those used by the Bt bacteria or normal herbicides) can't control. This could be like introduced invasive species on steroids.**
  - **Wide use of GMOs such as Bt will probably cause pests to evolve resistances. Thus "super pests" may be created (like over use of antibiotics create resistant staph bacteria)**
  - **What if corn genes that produce pharmaceuticals/plastics transfer to other food varieties of corn?**
  - **Organic growers varieties have been contaminated by normal wind borne cross pollination, thus rendering them useless (non-organic).**
    - In one case Monstanto then sued the organic farmer for unauthorized use their patented gene!

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GMO issues (continued)

- GM animals also are being made and have potential benefits and liabilities
  - Super salmon has genes that produce extra growth hormone so it grows seven times faster than normal salmon
  - Can produce more food in fish farms
  - But if salmon escapes into wild (which most believe must eventually happen) what will be result? Will ordinary salmon be out competed and wiped out? Will the ocean ecosystem be greatly changed?
- In order to protect patent rights, Monsanto produced GMO varieties (terminator technology) where the plant produces sterile seeds. Thus farmers could not save seeds (as is done worldwide) but would have to buy seeds from the patent owner.
  - This could give farmers much less control over what and how they grow food and more control to corporations.
  - After large protests Monsanto backed down and does not currently sell these, but the technology is being developed

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GMO issues (continued)

- Some also worry whether GMOs in food is safe to eat
  - New varieties of food have been produced by humans for millennia, but perhaps these are different. Will there be allergies?
  - Will vegetarians like have fish genes in their strawberries?
- Main problem may be the many unknown and unintended environmental consequences (ecosystems are very complicated)
  - e.g. claim Bt corn damages Monarch Butterfly (disputed)
  - GMO potatoes engineered to repel aphids, but found to attract other pests including potato leafeater
  - Some unapproved GMOs have already cross pollinated and already appeared in foodstuffs (e.g. unapproved starlink Bt gene was found in a large variety of consumer products)
  - Humans are again making radical changes to delicately balanced ecosystems, so the actual consequences are probably impossible to predict at this point.

Fish: the other important human food

- **Harvesting terrestrial wildlife (e.g. fish) could only feed a small fraction of the earth's existing population. Hunting wild animals has not been important for most humans for a long time. Wild populations were wiped out, and too much land needed.**
- **In the last decade, the world fish catch has leveled off and many species have become commercially extinct.**
  - **Commercial extinction means no longer economically viable**
- **Study in journal Nature says already more than 90% of all large fish in the ocean have now been harvested.**
- **Also, ocean pollution is damaging many species and may lower ocean productivity in the future.**
- **Red tides (surface algal blooms) are increasing all over the world**

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Figure 13.12: The collapse of a commercial fish population almost always creates financial hardship for fishing communities.

Figure 13.13: Red tide near La Jolla, California.

Courtesy of P. Alejandro Díaz

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How about fish farming? (aquiculture)

- **Currently fastest growing form of food production**
- **Currently 30% of world's fish produced by aquiculture, with China being number one. Will probably greatly increase. Over 200 species of fish now produced.**
- **Fish are more efficient than other animals in turning feed into flesh (cold blooded and need less muscle to support body because water holds them up).**
- **Issues: need lots of clean water, which is often fouled by the process. Organic wastes, chemicals, antibodies, etc. are released into the environment.**

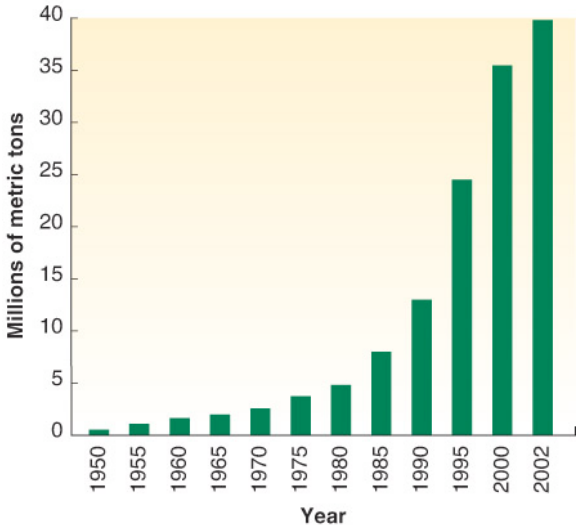

Figure 13.CS03_01: Global aquaculture production, 1950-2002, millions of metric tons per year.

Source: Adapted from Brown, LR, ed., *Vital Signs 2005* [New York, W.W. Norton, 2005], p. 27.

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Figure 13.CS03_02: An aquaculture facility in Louisiana raises catfish.

Courtesy of Scott Bauer/Agricultural Research Service/USDA

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