Cunningham Notes (from PJ Shlachtman)

What Are Pests and Pesticides?

- Biological Pests: organisms that reduce the availability, quality, or value of resources useful to humans.
    - Tend to be generalists
    - Reproduce rapidly
    - Migrate quickly into disturbed areas
    - Pioneers in ecological succession
    - Compete aggressively against more specialized endemic species
    - Can often take over a biotic community especially where humans have created an opening into which they can slip
- Pesticide: chemical that kills pests
    - Toxic substances
    - Chemicals that drive away pests
    - Chemicals that prevent their development
    - Biocide: broad-spectrum pesticide that kills all living organisms
    - Herbicide: pesticide that kills plants
    - Insecticide: pesticide that kills insects
    - Fungicides: pesticide that kills fungi

A Brief History of Pest Control

- Humans have probably always used chemicals to protect from pests, but during the past 50 years we have entered into a new era of pesticide use.

Early Pest Controls

- Use of metals and inorganic chemicals to control pests
    - Sumerians controlled insects and mites with sulfur 5000 years ago.
    - Chinese texts 2500 years old describe mercury and arsenic used to control body lice and other pests.
    - Greeks and Romans used oil sprays, ash, and sulfur ointments, and lime.
- Use of organic compounds, biological controls and cultural practices to control pests
    - Alcohol from fermentations to prevent the growth of organisms that would spoil food
    - Acids in pickling solutions to prevent the growth of organisms that would spoil food
    - Spices deterred spoilage and pest infestations
    - Romans burned fields and rotated crops to reduce crop disease.
    - Chinese developed plant-derived insecticides and introduced predatory ants in orchards to control caterpillars 1200 years ago.

Synthetic Chemical Pesticides

- Modern era of chemical pest control began in 1934 with discovery of DDT.
    - Used to control potato beetles
    - Important during WWII in areas where tropical disease and parasites were common.
    - Cheap, stable, soluble in oil
    - Highly toxic to insects; relatively non-toxic to mammals
    - It was sprayed on crops and houses and dusted on people and livestock.

Pesticide Uses and Types

- Pesticide sales have grown from almost nothing in 1950 to approximately 30 billion in 1999.
- 90% of pesticides worldwide used in agriculture, food storage, and shipping.

Pesticide Use in the United States and Canada

- 650,000 metric tons of pesticides used in U.S. in 1999.
    - Nearly 3/4 of all pesticides applied in U.S. are used in agriculture

Herbicides: 50%
Insecticides: 22%
Fungicides: 11%
Other types: 8%

- Germany and Italy use about 1/5 as much as U.S.
    - Canada uses about 1/10 as much as U.S. (doubled in past decade)

Pesticide Types

- Often classified by chemical structure
    - Inorganic pesticides (e.g. arsenic, copper, lead and mercury)
        - Generally highly toxic
        - Remain in soil forever
        - Generally neurotoxins
    - Natural organic pesticides (botanicals)
        - Extracted from plants
        - Nicotine: toxic to a broad spectrum of organisms
        - Rotenone: used to kill fish
        - Turpentine and phenols: effective pesticides
    - Fumigants (e.g. carbon tetrachloride, carbon disulfide)
        - Generally small molecules
        - Gasify easily
        - Penetrate rapidly into a variety of materials
        - Used to sterilize soil
        - Prevent decay or rodent and insect infestations of stored grain
        - Very dangerous to workers who apply them
        - Use has been curtailed or banned altogether
    - Chlorinated Hydrocarbons (organochlorines) (e.g. DDT, chlordane, aldrin)

        - Inhibit nerve membrane ion transport and block nerve signal transmission
        - Fast acting and highly toxic in sensitive organisms
        - Highly persistent in soil
        - Stored in fatty tissues of a variety of organisms
        - Become concentrated through food chains
    - Organophosphates (e.g. parathion, malathion)
        - Inhibit cholinesterase which is an enzyme essential for removing excess neurotransmitter from synapses in peripheral nervous system
        - Extremely toxic to mammals, birds, and fish
        - Less persistent in environment than organochlorines
    - Carbamates (e.g. carbaryl, aldicarb)
        - Share many organophosphate properties
        - Extremely toxic to bees
    - Microbial agents and biological controls
        - Living organisms or toxins derived from them used in place of pesticides
        - Some species of bacteria kill caterpillars or beetles by releasing a toxin that ruptures that digestive tract.
        - Some parasitic wasps attack moth and caterpillar eggs

Pesticide Benefits

Disease Control

- Insects and ticks serve as vectors in the transmission of a number of disease-causing pathogens and parasites
- Diseases spread by biting insects
    - Malaria
    - Yellow fever
    - Encephalitis
    - Sleeping sickness
- Diseases can be reduced by judicious use of pesticides.

Crop Protection

- Plant diseases, insect and bird predation, and competition by weeds reduce crop yields worldwide by at least 1/3.
- Without modern chemical pesticides, losses might be much higher.
- Farmers may save $3 to $5 for every $1 spent on pesticides.
    - Lower costs and generally better quality for consumers
- Cosmetic damage can greatly reduce the economic value of crops

Pesticide Problems

Effects on Nontarget Species

- Estimated that up to 90% of the pesticides we use never reach their intended targets.
- Many beneficial organisms are poisoned unintentionally as a result
    - Sometimes effects are immediate
    - Sometimes effects are not immediate and thus difficult to pin down

- A 1999 study linked insecticide (4-nonylphenol) spraying on Canadian forests with dramatic declines in Atlantic salmon.

Pesticide Resistance and Pest Resurgence

- Pesticides almost never kill 100% of a target species even under the most ideal conditions
- The most resistant members of a population survive pesticide treatment and produce more offspring like themselves with genes that enable them to withstand further chemical treatment.
- Pest resurgence: because most pests propagate rapidly and produce many offspring, the population will quickly rebound with pesticide resistant individuals.
- Pesticide treadmill: due to pesticide resistance, it takes constantly increasing doses to get the same effect.
- Despite a 33-fold increase in pesticide use, crop losses due to pests have actually increased.
- Many pests are resistant to chemicals to which they have never been exposed.
- DDT has been used so widely that 50/60 malaria-carrying mosquitoes are now resistant.

Creation of New Pests

- Broadcast pesticide spraying may kill beneficial predators that previously kept a number of pests under control
- Higher trophic levels are more likely to be knocked out than lower ones.

Table 12.1. Percentage of crops lost annually to pests in the UnitedStates

Year	Insects	Diseases	Weeds
1944	7.1	10.5	13.8
1974	13.0	12.0	8.0
1989	13.0	12.0	12.0

Source: Data from D. Pimentel, et al., "Environment and Economic Effects of Reducing Pesticides", *Bioscience*, 41:6-12, June 1991.

- Species that were previously insignificant can be released from natural controls and become major pests.

Persistence and Mobility in the Environment

- The qualities that make DDT and other chlorinated hydrocarbons so effective (stability, high solubility, and high toxicity), also make them environmental nightmares.
    - Some of the compounds have been discovered far from any possible source and long after they were used.
    - Can accumulate in polar regions through a series of evaporation, condensation, and precipitation events.
    - Have a high affinity for fat

        - Bio-concentrated and stored in bodies of predators (e.g. porpoises, whales, polar bears, trout, eagles, ospreys, and humans)
    - Breakdown by-products may still be present in the environment.
        - In a 1999 study, breakdown by-product of DDT, p,p'-DDE , is found in the amniotic fluid of 30% of a sample of pregnant women in Los Angeles, CA.
    - Atrazine and alochlor are widely used herbicides
        - 30% of all community wells and as much as 60% of all private wells in the mid-western corn belt are contaminated with atrazine and alochlor.
    - Because of the ubiquity of these persistent organic pollutants (POPs), there is a widespread movement to ban them.

Table 12.2. -- The "dirty dozen" persistent organic pollutants

Compound(s)	Uses
Aldrin	Insecticide used on corn, potatoes, cotton and for termite control
Chlordane	Insecticide used on vegetables, small grains, maize, sugarcane, fruits, nuts, and cotton
Dieldrin	Insecticide used on cotton, corn, potatoes, and for termite control
DDT	Insecticide, now used primarily for disease vector control
Endrin	Insecticide used on field crops such as cotton and grains and as a rodenticide
Hexachlorobenzene (HCB)	Fungicide used for seed treatment and as an industrial chemical
Heptachlor	Insecticide used against soil insects, termites, and grasshoppers
Mirex	Insecticide used to combat fire ants, termites, mealy bugs, and as a fire retardant
Toxaphene	A mixture of chemicals used as an insecticide on cotton as well as tick and mite control in livestock and fish eradication
Polychlorinatedbiphenyls (PCBs)	Industrial chemicals used as insulators in electrical transformers, solvents, paper coatings, and plasticizers
Dioxins	A large family of by-products of chlorinated chemical production and incineration
Furans	A large group of by-products of chlorinated chemical production and incineration

Human Health Problems

- Pesticide effects on human health can be divided into 2 categories

    - Short-term effects, including acute poisoning and illnesses caused by relatively high doses and accidental exposures.
    - Long-term effects suspected to include cancer, birth defects, and immunological problems, and other chronic degenerative diseases.
- The World Health Organization (WHO) estimates that between 2.5 and 5million people suffer from acute pesticide poisoning.
    - At least 2/3 of this illness and death results from occupational exposures in developing countries
- Long-term health effects difficult to document conclusively, however, links have been established.
    - Significant learning and attention problems in children whose mothers at Lake Michigan fish regularly
    - Children from farming communities where pesticide use is high had diminished growth and development as compared to children with minimal pesticide exposure

Alternatives to Current Pesticide Uses

- In many cases, improved management programs can cut pesticide use between 50 and 90% with reducing crop production or creating new diseases

Behavioral Changes

- Crop rotation (growing a different crop in a field each year in a 2-to6-year cycle) keeps pest populations from increasing.
- Mechanical cultivation can substitute for herbicide treatment, but can increase erosion
- Flooding fields before planting can suppress both weeds and insect pests.
- Burning crop residues and replanting with cover crop can suppress weeds and insect pests.
- Habitat diversification
- Growing crops where pests are absent
- Adjusting planting times can avoid pest outbreaks
- Switching from monoculture to mixed polyculture
- Tillage at certain times
- Important behavior adjustment comes in attitudes and preferences
    - Farmers should allow a few weeds to grow between rows.
    - Consumers should learn to accept fruits and vegetables that are less than perfect.

Biological Controls

- Biological controls: predators or pathogens that can control many pests more cheaply and safely than broad-spectrum, synthetic chemicals
    - Bacteria can be sprayed on crops to control pests.
    - Ducks, chickens, and gees can rid fields of both insects and weeds.
    - Insects including mantises and ladybugs protect against a multitude of pests.
    - Plants with insect-repelling properties such as garlic and marigolds.
    - Herbivorous insects can be used to control weeds.
    - Genetics and bioengineering
        - Breeding livestock that tolerate pests well

    - Hormones can be used to upset development or as sex attractants to bait traps containing toxic pesticides.
        - Beneficial insects as well as noxious ones may be negatively affected by hormone.

Integrated Pest Management

- Integrated pest management (IPM): flexible, ecologically based pest-control strategy that uses a combination of techniques applied at specific times, aimed at specific crops and pests.
    - Does not give up pest controls entirely.
    - Enhances growth and diversity of beneficial organisms.
    - Enhance plant defenses
- Economic thresholds: the point at which potential economic damage justifies pest control expenditures
    - Precise time, type, and method of pesticide application is critical in IPM
- IPM in use all over the United States on a variety of crops
    - Massachusetts apple growers using IPM have cut pesticide use 43% in the past 10 years.
- Most dramatic IPM stories come from third world countries such as Cuba, Costa Rica, Africa, and Indonesia.

Reducing Pesticide Exposure

- Pesticides used contain active ingredients combined with inactive carriers, solvents, preservatives, and other ingredients.
- Less than 10 % of active pesticide ingredients have undergone chronic health-effect tests.
- Studies of inactive ingredients have begun only recently

Regulating Pesticides

- Three federal agencies responsible for regulating pesticides used in food production in the United States.
    - Environmental Protection Agency (EPA)
    - Food and Drug Administration (FDA)
    - Department of Agriculture (USDA)
- Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA)
    - Under this act, EPA regulates the sale and use of pesticides
- Federal Food, Drug, and Cosmetic Act (FFDCA)
    - Under this act, EPA sets limits (tolerance levels) for the amount of pesticide residues that lawfully may remain in foods.
- Food and Drug Administration and Department of Agriculture enforce pesticide use and tolerance levels set by the EPA.
- Agriculture Canada is responsible for regulating pesticides used in food production in Canada.
    - Individual provinces can also set local standards.
- Delaney Clause

    - Amendment to the U.S. FFDCA in 1958.
    - Prohibited the addition of any known cancer-causing agent to processed foods, drugs, or cosmetics, therefore, is considered zero-risk
    - Difficult to enforce as many commonly used materials are carcinogens.
    - Further, it is impossible to test every one of the millions of natural and synthetic chemicals in our food.
        - Therefore, additives used before 1954 were considered safe.
        - Further, pesticides registered after 1978 were subject to this clause while those registered earlier were subject to less stringent standards.
    - In 1996, legislation was passed replacing Delaney's zero-risk requirement with that of reasonable certainty and of no harm (no more than 1 case of cancer for every million people exposed over a lifetime).
    - In 1999, following these new rules, EPA concluded children need an extra measure of protection.
        - Studies had shown that infants and children are more susceptible than adults to toxic pesticides.
- Many things can be done to minimize pesticides in our food and environment
    - Plant ground cover in your yard that can compete successfully with weeds.
    - Install or repair screens on doors and windows to keep out insects.
    - Clean up spilled food and empty garbage regularly to eliminate food for ants or roaches.
    - Get rid of houseplant pests by washing leaves and stems individually with rubbing alcohol.
    - A saucer of stale beer in your garden will attract and drown slugs.
    - Drain stagnant water in or near your yard that might serve as breeding sites for mosquitoes.
    - Accept slightly blemished fruits and vegetables.
    - If you use toxic pesticides, use them in the smallest possible amount and only when necessary.

Summary

- Biological pests are organisms that reduce the availability, quality, or value of resources useful to humans.
- Pesticides are chemicals intended to kill or drive away pests.
- Many beneficial organisms are injured by indiscriminate pesticide use.
- The war against pests entered a new phase with the invention of synthetic organic chemicals such as DDT.
    - Benefits of their use include increase crop production and control of disease-causing organisms.
    - Many problems resulted from their use.
        - Killing non target species
        - Creating new pests of organisms that were previously not a problem
        - Causing widespread pesticide resistance among pest species.
- Many alternatives to pesticide use exist.
    - Crop rotation
    - Cover crops
    - Mechanical cultivation
    - Planting mixed polycultures rather than monoculture fields
    - Biological controls such as insect predators and pathogens

    - Genetic breeding and biotechnology
- Integrated pest management (IPM) combines all of these alternative methods together with judicious use of synthetic pesticides under precisely controlled conditions.
- The Delaney Clause, an amendment to the Federal Food, Drug, and Cosmetic Act, prohibits willful addition of any known carcinogen to foods, drugs, or cosmetics.

Questions for Review

1. What is a pest and what are pesticides? What is the difference between a biocide, a herbicide, an insecticide, and a fungicide?
2. How much pesticide is used worldwide and in your country? In your country, which of the general categories of use and which specific type accounts for the greatest use? Has use been increasing or decreasing in recent years?
3. What is DDT and why was it considered a "magic bullet"? What are its benefits and disadvantages?
4. Describe fumigants, botanicals, chlorinated hydrocarbons, organophosphates, carbamates, and microbial pesticides.
5. Explain why pests often resurge or rebound after treatment with pesticides and how they become pesticide resistant. What is a pesticide treadmill and pesticide rain?
6. Identify three major categories of alternatives to synthetic pesticides and describe, briefly, how each one works.
7. How did Australia fight prickly pear cactus? How did Florida eradicate screwworms?
8. What is the Delaney Clause and why is it controversial?
9. List nine things you could do to reduce pesticide use in your home.
10. List eight things you could do to reduce your dietary exposure to pesticides.

Questions for Critical Thinking

1. In retrospect, do you think Paul Müller should have received a Nobel prize for discovering the insecticidal properties of DDT?
2. If you were a public health official in a country in which malaria, filariasis, or onchocerciasis were rampant, would you spray DDT to eradicate vector organisms? Would you spray it in your own house?
3. Pesticide treadmill, dirty dozen pesticides, and environmental estrogens are all highly emotional terms. Why would some people choose to use or not use these terms? Can you suggest alternative terms for the same phenomena that convey different values?
4. Many farm workers who suffer from pesticide poisoning are migrants or minorities. Is this evidence of environmental racism? What evidence would you look for to determine whether environmental justice is being served?
5. Suppose that a developing country believes that it needs a pesticide banned in the United States or Canada to feed or protect the health of its people. Are we right to refuse to sell that pesticide?
6. How much extra would you pay for organically grown food? How would you define organic in this context?
7. If alternative pest control methods are so effective and so much safer, why aren't farmers and consumers adopting them more rapidly?
8. If you were a member of Congress, would you vote to repeal the Delaney Clause to the FFDCA? Why or why not?

9. What would you personally consider a "negligible" risk? Would you eat grapes if you knew they had a measurable amount of some pesticide? How small would the amount have to be?
10. Why do you suppose that the Thompson's neighbors haven't adopted regenerative agriculture?