Case of the Dying Robins

Rob Keys, PhD Associate Professor of Science, Cornerstone University

Grade Level
7th Grade – High School Biology

Subject
Food Chains, Food Webs, Energy Transfer, Bioaccumulation

Rationale
Students need to understand how food chains and food webs function. This transfer of energy from one living organism to another is a key to understanding the complexity of ecosystems and the interrelationships that exist in our world. It is also key to understanding that energy is not the only thing that is passed, but that other chemical compounds can also be passed and magnified as they are consumed by each successive member of a food chain. This is bioaccumulation and biomagnification.

L2.p4A Classify different organisms based on how they obtain energy for growth and development. *(prerequisite)*
L2.p4B Explain how an organism obtains energy from the food it consumes. *(prerequisite)*
L3.p2A Describe common relationships among organisms and provide examples of producer/consumer, predator/prey, or parasite/host relationship. *(prerequisite)*
L3.p2B Describe common ecological relationships between and among species and their environments (competition, territory, carrying capacity, natural balance, population, dependence, survival, and other biotic and abiotic factors). *(prerequisite)*
L3.p3D Predict how changes in one population might affect other populations based upon their relationships in a food web. *(prerequisite)*
L3.p3D Predict how changes in one population might affect other populations based upon their relationships in a food web. *(prerequisite)*
B3.2B Describe energy transfer through an ecosystem, accounting for energy lost to the environment as heat.
B3.2C Draw the flow of energy through an ecosystem. Predict changes in the food web when one or more organisms are removed.
B3.4C Examine the negative impact of human activities.
B3.5e Recognize that and describe how the physical or chemical environment may influence the rate, extent, and nature of population dynamics within ecosystems.

Objectives
1. Students will describe various Great Lakes food chains.
2. Students will describe how various food chains interact with each other to create a food web.
3. Students will illustrate how energy is transferred through a system.
4. Students will investigate how human activities can negatively relate to the transfer of energy through a system.

Background Information

> *There once was a town in the heart of America where all life seemed to live in harmony with its surroundings. The town lay in the midst of a checkerboard of prosperous farms, with fields of grain and hillsides of orchards where, where, in spring, white clouds of bloom drifted above the green fields (p. 1).*

This seeming passerine setting is then shattered when a "strange blight" settles over the area and:

> *There was a strange stillness. The birds, for example – where had they gone? Many people spoke of them, puzzled and disturbed. The feeding stations in the backyards were deserted. The few birds seen anywhere were moribund; they trembled and could not fly. It was a spring without voices. On mornings that had once throbbed with the dawn chorus of robins, catbirds, doves jays, wrens, and scores of other bird voices there was now no sound; only silence lay over the fields and woods and marsh (p. 2).*

Thus Silent Spring (Carson 1962) began with the picture of quietness. Carson then, using the scientific data available to her at the time begins to establish her claims about pesticides and their effects on water, air and soil resources, wildlife, and humans.

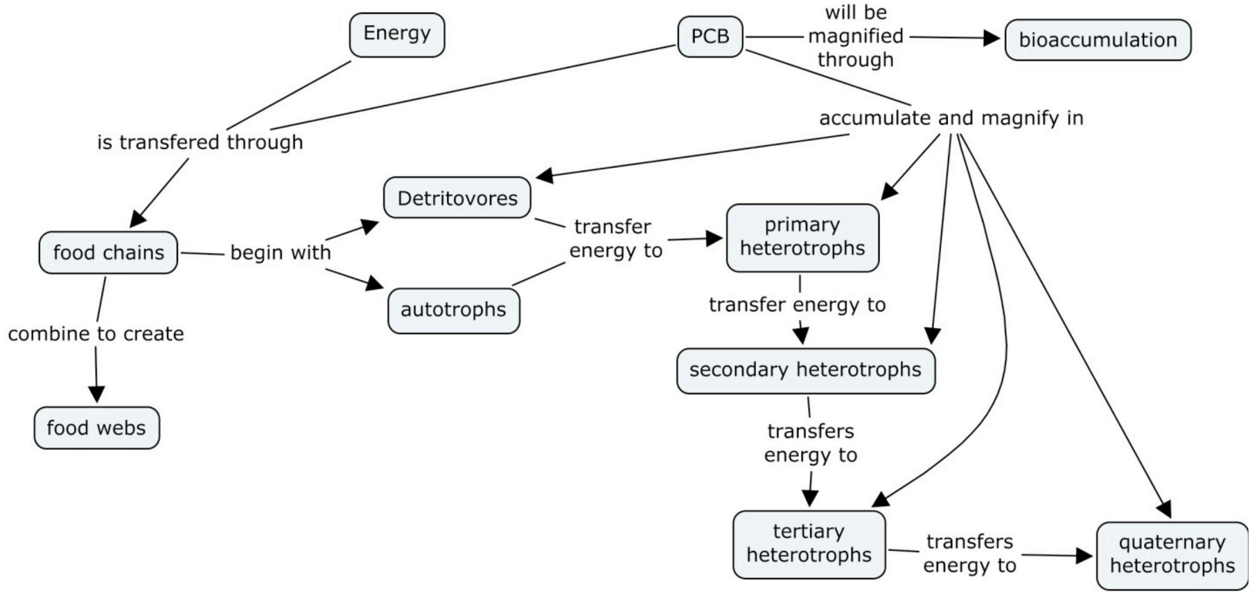
These claims began to form the exemplars for much of what was to occur in the scientific research of pesticides in the years following the publication of her book. Of concern here is the way in which she established the groundwork for research in what was to become known as bioaccumulation and biomagnification. In her seventh and eighth chapters Carson exposes study after study which indicate the link between pesticides and wildlife sickness and mortality. As she lays this groundwork she points out that many of these creatures would not be affected directly by the mass control sprayings, but rather seem to be victims of secondary causes. That is to say, they are victims of eating other animals which have ingested the pesticides. Though at this time no definitive link has been established, Carson proposes linkages which led to further research after the publication of her book. Of particular note are her references to the diminishing population of bald eagles. While no direct evidence points to it, Carson proposes the link between fish found with DDT concentrations in their bodies with the inability of eagles to lay eggs. Thus, the foundation for the study of bioaccumulation and biomagnification in wildlife had been laid.

While the use of DDT has been eliminated in North America, other chemicals still show the same bioaccumulative effects that DDT did back in Carson's day. The major chemical of concern in the Great Lakes region over the last 20 years has been PCB. While removed from the market in the 1970's, the effects of this chemical are long term in the environment, with many forms of it having little breakdown over time. These chemicals are magnified as you work from lower organisms in a system to the larger predatory fish. Research continues to show large quantities of PCB in the fatty tissues of bottom feeding fish such as Carp and Catfish as well as in the tissues of high level carnivores such as the Lake Trout.

Further information about the transfer and bioaccumulation of PCB's specifically within the Lake Michigan system can be found in Appendix A of this lesson.

Key Concepts

Food Chain	Food Web	Energy Transfer
Bioaccumulation	PCB	Autotroph
Primary Heterotroph	Secondary Hertotroph	Tertiary Heterotroph
Quaternary Heterotroph	Detritivore	



Materials

BioAccum Game Board
BioAccum Game Cards
Copy of the Rachel Carson Historical Vignette (Appendix B)
Movie clips from PBS *American Experience: Rachel Carson's Silent Spring (1993)*

Strategies and Activities

Engage

Review back to previous classes on food chains and webs. Have students review the idea that energy is passed from one trophic level to the next. Now ask students about the Great Lakes. What kind of energy transfer would we find taking place throughout this system? What would the lowest end of the food web look like? The top end? Tell students that today we will be investigating the question **"What path does energy take in a Great Lakes food chain and how do humans and other organisms have an impact on it?"**

Explore

Split the class into groups of four. Pass out a BioAccum Game Board to each group. Explain the object and rules of the game.

Object:

To be the first person to play all of the food cards on the board to get the Lake Trout to survive.

Rules:

1. Shuffle the cards and pass out seven (7) cards to each player. Remaining cards are placed in the center of the board as a draw pile. Each player should have seven (7) cards in their hand at any given time
2. Play begins with the player to the left of the dealer.
3. During a turn a player may do one of the following:
   a. discard up to 4 cards to the discard pile and draw up to 4 new cards. Cards may not be drawn from the discard pile.
   b. trade up to 4 cards with another player.
   c. play up to 4 cards on the board (including hazard cards on another player) and then draw cards to return their hand to seven (7) cards.
4. Hazard Cards
   Hazard cards may only be used once during a game. Once a hazard card is used it is set to the side. Any cards removed from the board through the use of a hazard card are returned to the discard pile.
5. When the game is coming toward the end players may not have seven (7) cards in their hands as there are only enough cards to complete the four food chains on the board.
6. Play ends when the first two players have completed their food chains.

Explain

Have the students explain their perceptions of the game to you. Was it fair that some players only had to fill one spot? What are the advantages of only having one source of food? Disadvantages?

At this point explain review that the closer an organism is to the source of energy (sun), the more energy it receives from that organism. However, there can also be drawbacks, in the form of invasive species (next lesson) and other human impacts. Query the students as to who was the first to finish the game. Explain that in the Great Lakes food web system not only is energy passed from organism to organism, but there are also human created chemicals which have been found in the tissues of animals. The key chemical is one called PCB – a fire retardant that was manufactured until the late 1970's in electrical insulation and other forms. However, over the years as these items have been discontinued the PCB's have been making their way into the environment, such that today there are harmful levels of PCB's in the Great Lakes system we just looked at. So, depending on which food chain you were in, you may not have come out of this game as healthy as you thought.

If you won with the food chain just eating the *Diporeia*, your levels of PCB's are over 4000 ng/g of fish – this is enough to kill the fish and cause serious health issues for anyone that eats the fish!

If you won with the food chain that included the *Diporeia* and smelt, you are not as bad off, however you still have enough PCB's in your system to kill the fish and cause health issues to anyone who eats you (3500 ng/g PCB).

If you won with the food chain that went from the phytoplankton to zooplankton to smelt you accumulated far fewer PCB's because you are going from a producer to a tertiary level heterotroph. Producers do not pick up as many PCB's as detritovores like the *Diporeia*. Your Lake Trout only has 1200 ng/g of PCB. Still a level of concern, but not hazardous.

If you won with the food chain that went from the phytoplankton to the Mysis to the Lake Trout you are actually in the best condition, with a PCB level of less than 1000 ng/g. Therefore, the people on this food chain actually in the long run win!

Elaboration

You have just received a letter from a friend that states the following:

'The mosquito control plane flew over our small town last summer. Since we live close to the marshes we were treated to several lethal doses, as the pilot criss-crossed over our place… We consider the spraying of active poison over private land to be a serious aerial intrusion. The "harmless" shower bath killed seven of our lovely song-birds outright. We picked up three dead bodies the next morning, right by the door … The next day three were scattered around the bird bath. I had emptied it and scrubbed it after the spraying, but YOU CAN NEVER KILL DDT. On the following day one robin dropped suddenly from a branch in our woods.

We were too heart-sick to hunt for other corpses. All of these birds died horribly, and in the same way. Their bills were gaping open and their splayed claws were drawn up to their breasts in agony. Air spraying where it is not needed or wanted is inhuman, undemocratic, and probably unconstitutional. For those of us who stand helplessly on the tortured earth, it is intolerable.'

You can read this letter while showing the segment (with no sound) of spraying taking place from American Experience: The Rachel Carson Story. This segment is pretty powerful, especially showing them spraying right on people.

Ask your students how they would respond to this letter. What is happening in the with the spraying? Is it killing the birds outright or is something else going on? What would they do? What action would they take? Have your students write their responses. Have your students respond using the ideas that they developed from playing the BioAccum Game.

If you wished, you could introduce students to the historical figure of Rachel Carson, the one who actually received this letter, which then prompted her to write the best-selling and world changing book *Silent Spring*, which started the modern environmental movement.

Evaluation

Use the letters from the elaboration portion of the lesson to evaluate students on the use of concepts relating to energy flow in food chains and the bioaccumulation of chemicals in the bodies of the upper level heterotrophs.

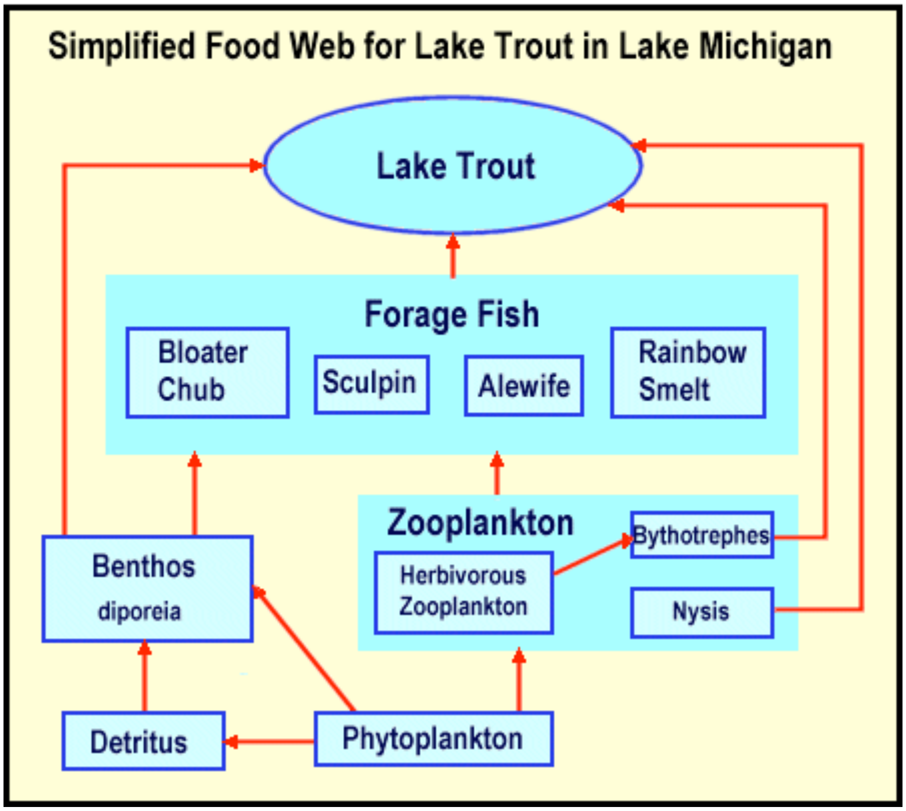
Appendix A

Food Web Bioaccumulation Model

http://www.epa.gov/glnpo/lmmb/foodweb.html

A bioaccumulation model simulates chemical accumulation in the food web in response t chemical exposure, based upon chemical mass balances for aquatic **biota** (living matter). The general form of the bioaccumulation equation is well-defined, and equates the rate of change in chemical concentration within a fish (or other aquatic organism) the sum of chemical fluxes into and out of the animal. These fulxes include direct uptake of chemcal from water, the flux of chemical into the animal through feeding, and the loss of checmialc due to elimination (desorption and excretion) and dilution due to growth. To predict bioaccumulation for top predator fish (the modeling objective here), the bioaccumulation mass balance is repeatedly applie to animals at each trophic level to simulate chemical biomagnification from primary and secondary producers, through forage species to top predators. Food web bioaccumulation models have been successfully applied for PCBs and other HOCs in several large-scale aquatic ecosystems, (*Thomann and Connolly, 1984; Connolly and Tonelli, 1985*), and, most recently, for the Green Bay Mass Balance Study (*Connolly et al., 1992*). The model developed for that project, FDCHN, will be adapted for use in Lake Michigan. FDCHN is a time-variable, population-based age class model., incorporating realistic descriptions of bioenergetic, trophodynamic, and toxicokinetic processes. The general features of FDCHN are well-suited to a modeling application such as the [LMMB].

For Lake Michigan, bioaccumulation of PCB congeners and TNC will be modeled for lake trout and coho salmon food webs. Food web bioaccumulation will be simulated for sub-populations of lake trout in three distinct biotic zones. The general structure of the lake trout food web in Lake Michigan is:



In each zone, different food webs support lake trout, including benthic and pelagic food web linkages. Biotic zones are defined by the approximately 50-mile range of movement of lake trout. The coho salmon, in comparison, is strictly pelagic. Although the coho food web is simpler, the bioaccumulation simulation must account for significant migration over the two-year lifetime of this stocked salmonid in Lake Michigan.

It should be recognized the FDCHN, and []all current food web bioaccumulation models, is not predictive in terms of the dynamics of the food web itself. In other words, the food web structure is described as model input. FDCHN does not predict changing forage composition, trophic status, in response to nutrients, exotic species invasion, or fisheries management. Yet such factors have been demonstrated to alter food web structures in the Great Lakes, and these changes have been suggested to affect bioaccumulation in top predators including salmonids. To address the sensitivity of bioaccumulation predictions to food web dynamics, the SIMPLE model (*Jones, Koonce, and O'Gorman; 1993*), a bioenergetic model for fish population dynamics in the Great Lakes, will be used to construct scenarios for food web change that will then be tested in FDCHN. While less satisfactory than an integrated population dynamics simulation, such testing will demonstrate the sensitivity of bioaccumulation predictions to food web dynamics in comparison to changes in contaminant concentrations in fish due to reducing exposure concentrations.

Atrazine bioaccumulation will not be modeled, because it is not expected to accumulate in biota due to its low hydrophobicity. It is not presently feasible to model bioaccumulation of mercury because a mass balance for the bioaccumulative fraction (the methyl species) is beyond present analytical and modeling capabilities. As identified in *Mercury in the Great Lakes; Management and Strategy (Rossmann and Endicott, 1992)*, the development of such capabilities must initially take place on small, constrained ecosystems as opposed to the Great Lakes. This is consistent with the research approach of Porcella et al. (1992) in developing the EPRI Mercury Cycling Model, which was based upon data gathered from the Little Rock Lake and other bog seepage lakes in Wisconsin.

A number of FDCHN enhancements will be considered in the Lake Michigan application. These include incorporating specialized sub-models for phytoplankton (*Swackhamer and Skoglund, 1993*) and Diporeia (*Landrum *et al., 1992*), the organisms at the base of the pelagic and benthic food webs. The bioaccumulation press formulations of Gobas (1993), Barber et al. (1991) and Sijm et al. (1992) will be reviewed for possible updating of FDCHN toxicokinetic descriptions. The detailed bioenergetics model of Hewett and Johnson (1987, 1989) which is currently employed in simplified form in FDCHN, may also be more fully incorporated in the model.

Results of the Lake Michigan Mass Balance Study: Polychlorinated Biphenyls and trans-Nonachlor Data Report

April 2004

The U.S. Environmental Protection Agency's Great Lakes National Program Office (GLNPO) and its partners instituted the Lake Michigan Mass Balance (LMMB) Study to measure and model the concentrations of representative pollutants within important compartments of the Lake Michigan ecosystem. The goal of the LMMB Study was to develop a sound, scientific base of information to guide future toxic load reduction efforts at the Federal, State, Tribal, and local levels. Objectives of the study were to:

1. Estimate pollutant loading rates,
2. Establish a baseline to gauge future progress,
3. Predict the benefits associated with load reductions, and
4. Further understand ecosystem dynamics.

http://www.epa.gov/glnpo/lmmb/results/pcb/index.html

PCBs and trans-Nonachlor in Lower Pelagic Food Web Organisms

PCB and trans-nonachlor concentrations measured in the lower pelagic food web differed significantly among phytoplankton, zooplankton, Mysis spp., and Diporeia spp. Concentrations of total PCBs and trans-nonachlor were highest in samples of Diporeia spp., followed by Mysis spp., zooplankton, and phytoplankton, respectively. Total PCB concentrations were 9 times higher in Diporeia spp. than in phytoplankton, averaging 420, 250, 170, and 49 ng/g dry weight in Diporeia spp., Mysis spp., zooplankton, and phytoplankton samples, respectively. Trans-Nonachlor concentrations were 19 times higher in Diporeia spp. than in phytoplankton, averaging 32, 25, 16, and 1.7 ng/g dry weight in Diporeia spp., Mysis spp., zooplankton, and phytoplankton samples, respectively.

A portion of the difference in PCB and trans-nonachlor concentrations among lower pelagic food web sample types is likely due to variations in the lipid content of the samples. Hydrophobic organic contaminants such as PCBs and trans-nonachlor preferentially concentrate in the fatty tissues of organisms, so those organisms with higher lipid content will likely concentrate more of these contaminants. The differences in lipid content among the sample types, however, explained only a quarter to less than half of the variability in total PCB and trans-nonachlor concentrations. Even when total PCB and trans-nonachlor concentrations were normalized by lipid content, the trends in PCB and trans-nonachlor concentrations among the sample types were almost always the same. Normalized total PCB and trans-nonachlor concentrations in Diporeia spp. and Mysis spp. were significantly higher than in zooplankton and phytoplankton, and normalized trans-nonachlor concentrations in zooplankton were significantly higher than in phytoplankton. Normalized total PCB concentrations in zooplankton, however, were not significantly different than in phytoplankton.

PCBs and trans-Nonachlor in Fish

PCB and trans-nonachlor concentrations differed significantly among species. Significantly higher levels of total PCBs and trans-nonachlor were observed in Lake trout, a top predator in the Lake Michigan pelagic food web, than in any other fish species. Mean wet-weight concentrations of total PCBs and trans-nonachlor in lake trout were 3.6 and 2.9 times higher than for any other species. This trend was similar for dry-weight basis PCB and trans-nonachlor concentrations. Mean dry-weight basis total PCB concentrations in lake trout were from 1.2 to 16 times higher than in other species, and mean dry-weight basis trans-nonachlor concentrations were 2.4 to 34 times higher in lake trout than in other species.

When PCB and trans-nonachlor concentrations were compared among fish species on a lipid-normalized basis, lake trout still contained higher levels of contamination than all other species with the exception of adult coho salmon. Mean lipid-normalized total PCB and trans-nonachlor concentrations were highest in adult coho salmon and second highest in lake trout. Lipid-normalized total PCB and trans-nonachlor concentrations in these two top predator fish species were significantly higher than in any of the forage fish species. The higher mean concentrations of lipid-normalized contaminants in adult coho salmon were due to the relatively low lipid content in this species. Lipid content in adult coho salmon averaged only 4%, compared to 16% in lake trout. Of the species analyzed in this study, only smelt contained lower lipid content (3.6%) than adult coho salmon.

The lowest total PCB and trans-nonachlor concentrations on a wet-weight, dry-weight, or lipid-weight basis were consistently found in hatchery and yearling coho salmon. This species is raised in hatcheries and annually stocked in Lake Michigan. Hatchery samples consisted of immature coho collected directly from the Platte River hatchery, and yearling samples consisted of immature coho collected in Lake Michigan. The reduced contamination in these sample types most likely reflects both the young age of the fish and reduced contaminant exposure from hatchery food and water sources.

The Great Lakes Fish Consumption Advisory Task Force has set a fish advisory category of “no consumption” at PCB levels above 2000 ng/g, and established four lesser consumption categories ranging form unrestricted consumption to no more than 6 meals per year. Of the Lake Michigan fish analyzed in the LMMB Study, only lake trout contained PCBs above the 2000 ng/g level. In fact, 56% of lake trout samples exceeded this tolerance level, and the mean total PCB concentration for Lake Michigan lake trout was 3000 ng/g (or 3 ppm), which is 50% above the 2000 ng/g tolerance level. No coho salmon or lake trout samples fell into the unrestricted consumption category. Coho salmon primarily fell into the 1 meal/mo and 6 meals/yr categories. These categories contained 46% and 44% of coho salmon samples, respectively, with only 9% of coho salmon samples falling into the 1 meal/wk category. Lake trout primarily fell into the no consumption category (56%), with only 0.4%, 17%, and 26% in the 1 meal/wk, 1 meal/mo, and 6 meals/yr categories, respectively.

Appendix B

Rachel Carson's Reception of Olga Huckins Letter: A Fictional Historical Vignette

It was a cold and wet January in the winter of 1956. It had rained more than snowed in the suburb of Silver Springs, Maryland, just outside of Washington, D.C. In the home of Rachel Carson, Rachel continued to work on her writing as well as take care of her mother and nephew Roger. However, on this day, Rachel did not seem to notice the weather outside. The mail had just been delivered, and in it was a letter that would change the rest of her life.

"Mother, do you remember Olga Huckins, the book reviewer for the Boston Globe?" Rachel commented as she came into her mother's room.

"Isn't she the one with the nice property in Duxbury that they have set aside as a sanctuary for birds?" her mother responded.

"Yes, that's her," answered Rachel. "I have a nice letter from her here today. Well, let me rephrase that, while it's nice to hear from her, it contains some disturbing news."

"Why don't you sit down and read it to me," replied her mother.

"I won't tire you with the whole thing. She says she and her husband are doing well, but here is the disturbing part. Here, let me get to it." Rachel turns the pages of the letter to the appropriate part. " She is talking about an event from summer last. She says, 'The mosquito control plane flew over our small town last summer. Since we live close to the marshes we were treated to several lethal doses, as the pilot criss-crossed over our place… We consider the spraying of active poison over private land to be a serious aerial intrusion."

Mother Carson interrupts, "I should not think that anything out of the ordinary Rachel, those planes are everywhere today. The television even shows them spraying that material right on the top of people and they don't seem to be affected by it. In fact, the other day I saw a piece where they were spraying the DDT out of hoses along streets where people were walking, over pools where people were swimming and even over a picnicking area where people were eating."

"Yes, I have seen those pieces too. Yet, they bother me. Here, she goes on Mother," responds Rachel. "Listen to this, it sounds like what I have been hearing from some of my former colleagues at the Fish and Wildlife Service. She continues, 'The "harmless" shower bath killed seven of our lovely song-birds outright. We picked up three dead bodies the next morning, right by the door … The next day three were scattered around the bird bath. I had emptied it and scrubbed it after the spraying, but YOU CAN NEVER KILL DDT. On the following day one robin dropped suddenly from a branch in our woods.

We were too heart-sick to hunt for other corpses. All of these birds died horribly, and in the same way. Their bills were gaping open and their splayed claws were drawn up to their breasts in agony.

Air spraying where it is not needed or wanted is inhuman, undemocratic, and probably unconstitutional. For those of us who stand helplessly on the tortured earth, it is intolerable.'"

Silence hangs in the room as Rachel finishes reading.

"How awful," her mother breaks the silence in a quiet voice. "I cannot imagine what that would be like to find beautiful birds in such a way."

"I know how you feel Mother," rejoins Rachel. "I too cannot fathom such a scene. Imagine if that happened at our wonderful retreat in Maine. We would be devastated."

"But I thought those chemicals were safe," Mother Carson challenges.

“There must be more to it than we know. Olga wishes for me to find some answers. Someone out there must know something about these things,” Rachel replies.

“Yes dear, you must. Write back to Olga and tell her you will.”

Rachel’s life was never the same after that point. When she inquired about these pesticides she found that there was quite a bit of research about their harmful effects, but it was in places that the general public would never hear about. In fact, save for one journal and some other ancillary publications, the word about pesticides was not getting out at all. Rachel tried to get some of her scientist colleagues to publish a book about their and others’ findings, but no one was willing to risk their job to do so. She even approached Reader’s Digest about doing an article for them about the problem, but they too turned her down. So, Rachel took it upon herself to write a book about pesticides. Silent Spring would forever change the way people look at pesticides.

Reference:

Goodwin, Neil. (Writer). (1993). Rachel Carson’s silent spring [Television series episode]. In N. Goodwin (Producer), American Experience. Boston: WGBH Educational Foundation.

Sterling, Phillip. (1970). Sea and Earth: The Life of Rachel Carson. New York: Thomas Y. Crowell Company.