Ecological Magnification

Environment/Technology
by
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A commonplace observation in monitoring persistent chlorinated hydrocarbons is that residue concentrations are much higher in predatory animals than in other organisms or in the general environment. Usually residue levels are higher in herbivorous animals than in plants, higher in carnivorous animals than in herbivores, highest of all in carnivores that feed on carnivores. The spectacularly high concentrations of DDE and PCBs are thus found found in fish-eating birds (such as ospreys and pelicans), bird-eating birds (such as falcons) and fish-eating mammals (such as seals and porpoises).

Scientists commonly account for these frequencies by describing persistent chemicals as "ecologically magnified" or "accumulated in food chains." With the proviso that most animals feed on more than one type of prey — so that we should speak rather of "food webs" than "food chains" — this serves as a fairly good empirical generalization. However, the simple word "accumulation" presents a misleading impression of the underlying mechanisms' simplicity: Detailed studies show that the phenomenon is quite complex and biologically interesting.

Many features of ecological magnification can be duplicated and studied under controlled conditions in the laboratory. In one simple aquarium experiment, algae accumulated dieldrin to levels 1,300 times higher than that in the ambient water, water-fleas to levels 11 times those in the algae; and guppies to levels 3.5 times those in the water-fleas. More sophisticated "model ecosystems," incorporating both terrestial and aquatic plants and animals, have been designed at the University of Illinois. In these systems the highest concentrations were consistently observed in fish (predators) and snails (scavengers). A number of different chemicals have now been tested under identical conditions in these systems: The measured degree of ecological magnification is very closely correlated with and inversely proportional to the water-solubility of the chemical. Thus the principal force behind the phenomenon of ecological magnification appears to be the partitioning of the chemicals between water and fat-containing organisms: The less soluble the chemicals are in water, the more strongly they are taken up into plants and animals.

A simple partitioning theory does not work quantitatively, however. Partition coefficients for DDT and DDE between fat and water are of the order of 10^6 to 10^8; yet in controlled experiments bio-accumulation factors (ratios of chemical levels in organisms to levels in ambient water) rarely exceed 10^5. Thus the degree of accumulation must be limited by biological rather than physico-chemical processes.

The Equilibrium Theory

When organisms are exposed to constant levels of chlorinated hydrocarbons (either in their food or, in the case of aquatic organisms, in their water environment), the concentrations of the chemicals rise rapidly at first and then level off to reach a quasi-equilibrium. At this point the rate of chemical intake is more or less balanced by the rates of excretion and of metabolic breakdown. The slower the rate of excretion, the longer the time required to reach equilibrium and the higher the concentration in the tissues. As it happens, experiments show a good general correlation between the size of the organism and the time required to reach equilibrium. In experiments with DDT and PCBs, for example, approximate equilibrium is reached in a matter of hours in algae, days in crustaceans, weeks or months in fish, months in birds and small mammals, and several years in humans. Thus larger animals generally have more difficulty excreting these chemicals than do smaller organisms — a difference that probably has something to do with their lower metabolic rates and surface-to-volume ratios. Since predators are generally larger than their prey, this metabolic difference goes far to explain the phenomenon of ecological magnification.

So far, we have expressed in the term "ecological magnification" two rather different phenomena. Terrestial animals (including man) ingest these chemicals primarily in their food — or sometimes by inhalation. However, aquatic animals such as fish and crustaceans ingest the chemicals both in their food and directly from the water in which they live; they have to process so much water in order to obtain oxygen that the water is usually the primary route of exposure to toxic chemicals. The mechanisms are so different they are often given different names: For an aquatic animal, the uptake of a chemical from ambient water is termed "bio-accumulation"; for an air-breathing animal, uptake of a chemical from food is called "bio-magnification." "Bio-accumulation factors" for persistent chlorinated hydrocarbons are typically in the range of 10^3 to 10^5 in laboratory conditions, but "bio-magnification factors" are much more modest — typically around ten for DDT and PCBs and around one for more water-soluble chemicals such as dieldrin and lindane.

In addition to the quasi-equilibrium established between an organism and its external environment, there often appears to be an equilibrium distribution of the chemical within the organism. If the ex-

Spectacularly high levels of chlorinated hydrocarbons have been found in fish-eating birds such as this brown pelican. Scavenging animals are particularly susceptible, as their diet is more likely to include prey which has died or been weakened by exposure to the chemicals.

posed animals are killed and dissected, the chemical is often found distributed among organs in a more or less constant and predictable fashion. According to the most plausible model, the chemical is absorbed into the animal and circulated through the body in the blood, reaching an independent equilibrium across the membranes which separate the blood from each organ in the body. Studies of the distribution of dieldrin in man, for example, show that it is partitioned between the blood, brain, liver, and fat in the ratios 1:4:23:136 respectively. DDE and PCBs are still more strongly partitioned into fat. The more fat an animal contains, therefore, the higher will be its average body concentration and the higher the ecological magnification ratio calculated on a whole-body basis. As a general rule, predatory animals tend to be fatter than their prey, so this fact alone contributes to the phenomenon of ecological magnification.

Non-Equilibrium in the Real World

Like most simple theories based on a few highly-controlled experiments, the equilibrium theory does not work too well in the real world. In the first place, no wild animal is ever exposed to constant levels of a chemical: Environmental residues are highly variable in space and time, so that it is unlikely that the ideal equilibrium is ever reached — except in an abstract statistical sense. For large animals, the time required to reach quasi-equilibrium is longer than annual cycles of physiological condition. Under recurrent stresses of food shortage, reproduction, etc, many wild animals deplete their fat stores periodically, releasing fat-soluble chemicals to circulate through the body at high concentrations.

Worse still, there is mounting evidence that the equilibrium theory may rest on an unsound empirical base. Several experimental studies on various animal species exposed to dieldrin have shown that tissue concentrations reach a quasi-equilibrium after about one year of exposure but then start to rise sharply again after two years. Since most research projects are funded for only about two years, we know little

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the only consideration in saving a bucket of soil. There are issues of food: provision, growing, harvesting, storing, and preparing; of water management: collection, control, and purification; of waste management: diverse uses of waste, returning it to the soil, and using it for energy; of transportation; of communication; of education, of people.

One hopes C.R.S. has learned a lot about energy conservation by preparing this book and in the future will consider buildings in the broadest context of environmental planning, taking into account not only energy savings but all other forms of life-support systems as well. Architecture, a dying profession, must expand its horizons from a wholly aesthetic/form/goal-oriented endeavor to one dedicated to providing people with meaningful environments that fully enhance the experience of living and that allow us to discover who we are in the context of the total world and the natural environment.

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Letters

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Should This Trip Be Up, Not In?

It seems to me that our cities need to go up, not out, in order to save commuting *(see "Is This Trip Really Necessary?" December, 1974, p. 64)*. A cluster city might have, say, eight skyscrapers possibly arranged around a park one-quarter mile in diameter. Each would have a purpose: offices, apartments, schools, recreation, medical, shopping, light fabrication, and car rentals. Surrounding the cluster would be tennis courts, soccer fields, garden plots, etc., for at least five miles. While currently people may prefer to "live away from work," they currently "live away from play" too. As car prices, gasoline prices, parking costs, and travel times increase, the idea of riding an elevator to work or to a tennis court gets more and more appealing. For vacation or trips to the next cluster city, one could rent a car.

This concept has been started in Washington, D.C., where apartments are now being built next to offices. Adding the buildings for other purposes could come soon — and would require, I might add, a lot more thought on *balance* than I have given it. And some thought on how to use two extra hours a day, too.

Alan Pope
Albuquerque, N.M.

Butchering Medicine

As a Doctor of Medicine and Surgery, I deeply resent the headline "Science Comes to Medicine - Slowly" by Mr. Victor Cohn *(December, 1974, pp. 8-9)*. There is much more to the "science of medicine" than the randomized double-blind controlled study that Mr. Cohn holds as his paragon of knowledge and truth. Dismissing all who came before Mayo as bumbling butchers crazed by the thrill of the knife does a disservice to a profession that since ancient times has led the attempt at finding scientific explanations for natural happenings and whose literature is probably the most voluminous ever recorded. Journalism's "scientific accomplishments" should only hope to be as great.

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The headline is the editors' — not Mr. Cohn's — responsibility. — Ed.

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about this phenomenon. However, in man — although tissue levels of DDT appear to have reached equilibrium some time ago — those of DDE rise constantly with age — an observation hard to reconcile with the equilibrium theory.

Worst of all, laboratory studies now seem to underestimate grossly the potential for ecological magnification in the natural environment. In Lake Michigan, for example, the average concentrations of DDT and dieldrin in the lake water are in the range of 1 to 3 parts per trillion. Typical concentrations in fish are in the range of 0.2 and 10 parts per million, representing ecological magnification factors of roughly 3×10^6 and 10^9, respectively. Yet under experimental conditions ecological magnification factors for these chemicals in fish rarely, if ever, exceed 10^8 and 5×10^8, respectively. Evidently some phenomenon leads to magnification 20 to 30 times greater in the wild than in the laboratory. Many similar examples could be cited involving unexpectedly high concentrations in wild fish, birds, and mammals.

One factor contributing to these anomalies is that the chemicals are distributed patchily in the environment and tend to be concentrated in biologically productive areas (e.g., sewage effluents or natural surface slicks). Predatory animals tend to concentrate their activities in such areas, and they thus selectively expose themselves to high levels of pollutants. Probably a more important factor is selective predation: It is well known that predators selectively take prey whose behavior is abnormal, and several studies have shown that they tend to select prey with above-average residues of chlorinated hydrocarbons. Selective exposure is a particular hazard to scavenging animals — those which eat dead or moribund prey — who are thus in danger of selecting poisoned individuals. We urgently need more critical study of these processes. However, it is becoming clear that ecological magnification of toxic chemicals is a phenomenon ultimately controlled by ecological variables and not by the physiological or physicochemical factors usually studied in the laboratory.

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and N. Richard Werthamer, solid-state physicist from Bell Laboratories, were sponsored by A.P.S.; and Ronal Larson, Associate Professor of Electrical Engineering at Georgia Tech, joined as an I.E.E.E. fellow.

By the time these fellows arrived in Washington in September, Dr. Hyman, the A.S.M.E. fellow who had been with the Senate Commerce Committee staff since early spring, had clearly demonstrated that a technical person on a fellowship basis could make significant contributions to Congressional staff work and win the respect and admiration of his peers. Dr. Hyman had become an energy conservation expert for the staff, the organizer of an important energy conservation hearing held before the Committee several months before the "energy crisis."

The tension that preceded the arrival of the new Congressional fellows gave way during their two-week orientation to a free exchange that revealed a lot about the curiosity, misconceptions, and mutual interests of the new fellows and the "old pols." One Congressman's administrative assistant reminded the fellows that their presence probably meant a tripling or quadrupling of the total technical staff capability of Congress. A veteran staff member warned them, "As outsiders, don't expect to accomplish much. You'll probably spend most of your time addressing envelopes and answering constituent mail." A Senator beamed and said, "We need you. You're welcome with open arms."

The fellows, having a snappy two-week cram course in the institution they were about to serve, learned that privacy does not exist if you work in Congress and that the quiet office or laboratory from which they had come would only be something to dream about over the next several months.