THERMAL EFFECTS ON ECOLOGICAL SYSTEMS

THERMAL EFFECTS ON ECOLOGICAL SYSTEMS

A. F. Bartsch, Director
Pacific Northwest Water Laboratory, Federal Water Pollution Control Administration, Dept. of the Interior, Corvallis, Oregon.

and

D. I. Mount, Director
National Water Quality Laboratory, Federal Water Pollution Control Administration, Dept. of the Interior, Duluth, Minnesota.

"Temperature, a catalyst, a depressant, an activator, a restrictor, a stimulator, a controller, a killer is one of the most important and most influential water quality characteristics to life in water. Temperature determines those species that may be present; it activates the hatching of young, regulates their activity and stimulates or suppresses their growth and development; it attracts, and kills when the water becomes too hot or becomes chilled too suddenly. Colder water generally suppresses development; warmer water generally accelerates activity and may be a primary cause of aquatic plant nuisances when other environmental factors are suitable."

What I have just read is taken verbatim from the Introduction of a Federal Water Pollution Control Administration report titled "Temperature and Aquatic Life." (1) It points to many of the considerations that arise when we think of thermal effects on ecological systems.

So that all of us are thinking in the same terms, let me define this now popular word "ecology" as the study of the interrelationships between organisms and their environment. We are concerned today with environments that are modified through augmented heat input. There are three ecological aspects I wish to explore: (1) the broad implications for this planet, (2) effects on ecological systems in the water environment, and (3) potential uses of heat.

Implications for This Planet

In the current issue of BioScience, (2) LaMont C. Cole, currently President of the American Institute of Biological Sciences, examines the earth's heat budget and man's effect on it. Let me briefly paraphrase his analysis for you.

Of all the earth's sources of energy, 99.999% reaches us as radiation from the sun. Through photosynthesis over the ages, some energy from this source has been stored in organic fuels which, at some future time, may release heat into the environment. Heat also emerges from the center of the earth, perhaps from natural radioactivity. There are several other minor heat sources.

If the surface of the earth is to maintain its present mean tempera: which lies in the neighborhood of 59°F, it must rid itself of a quantity o: heat equal to the input. This is important because a mean temperature ri of only 5.4°F is believed likely to melt the icecaps of Greenland and Antarctica, raise the sea level by some 328 feet, put Florida under water and drown most of the world's major cities. For this to happen would require only a 4.2% increase in the earth's heat budget.

So, let's look at what people do to the heat budget. The amount o: energy now being produced by man is exceedingly trivial--only about 25/ of 1% of the total radiated by the earth. It is thus obvious that this act now has an absolutely insignificant direct effect on the average tempera of the earth's surface. But the question is--Will this still be true as we go on increasing our demands for power? What will happen, for example if power production and non-electrical uses of fuel increase at the now anticipated rate of 7% per year? The answer is that in 91 years there co be a warming of 1.8°F, which could result in some shifts in plant commu distribution. But to reach that critical 5.4°F increase and face all the di consequences I mentioned would take about ~~780~~ 108 years! Well, that's fine and so let's relax, but let's also keep this prospect in the back of our mi as we concentrate on the more urgent problems that are here today.

Responses to Heat in the Water Environment

So our planet seems secure; let's go on then to examine the respons to heat in the smaller sphere of the water environment.

As temperature in water environments rises, the rates of various chemical and biochemical reactions are accelerated. Production of hydro sulfide in bottom sludges doubles with a rise of 18°F. The BOD reaction, by which organic matter is stabilized, is most rapid at 86°F, so that a stream may be cleansed of its waste load more quickly as temperature goe up. But this accomplishment is not without cost. As dissolved oxygen is used up more rapidly to satisfy the needs of the process, rising temperature impairs reaeration. As a result, the stream's oxygen resources diminish, and all the undesirable side effects of oxygen depletion can come into being. Elevated temperature has been noted to substantially reduce the assimilation capacity in some rivers.(3) As a result, waste treatment performance must be improved or streamflow for dilution must be increased.(4)

These and many other responses help to create a new heat-modified environment to which living organisms must respond. Through its influenc on molecular movement and speed of chemical reactions, temperature con the rate of metabolism and activity of all organisms. This applies to aquatic plants. It is true of animals that can maintain a relatively constant temperature; it also affects those whose temperature approximates that of the environment---the so-called cold-blooded animals. For this reason, temperature may be the most important single environmental factor affecting life and life processes.

Aquatic algae are affected profoundly by temperature changes (Fig. 1). From 68-75°F, diatoms dominate the algal population. As temperatures rise to 86-95°F, green algae are most common. Above 95°F, blue-green algae predominate. No one has a good word to say for blue-green algae. They are unattractive as food for aquatic life, they cause blooms and drifting windrows of stinking scum, they destroy recreation, and create difficult and costly water supply problems. Sometimes, especially in the Midwest, they even become toxic and cause catastrophic deaths of livestock, game animals, birds, and fish.

We are concerned on a national scale with the exploding problem of eutrophication, or lake aging. The most distasteful symptom is the abundance of these same unwanted blue-green algae. The principal remedial attack now used is to limit the input of stimulatory plant nutrients through tertiary treatment of municipal sewage. Apparently now we must keep an eye on the heat budgets of susceptible waters as well.

It has been known since the turn of the century that the characteristics of bottom-dwelling organism populations are clues to the quality of the environment. When the habitat becomes more stringent, as it does from the addition of pollutants, the variety of surviving organisms becomes progressively less. This commonly known principle is the basis for diagnostic schemes still used to detect and measure pollution. Studies on a Pennsylvania stream [5] show this principle is valid for elevated temperature, also (Fig. 2). The number of kinds of organisms decreased by 55% as temperature went up from 80 to 87°F. When temperature increased further to 93°F, there was a 24% additional loss. Such population changes under the influence of heat are an important reason for concern. Because these organisms are the food of sport and commercial fishes, they need to be preserved, for without them the fisheries also will disappear.

The physiologist considers a number of vital mechanisms when he is concerned with the direct impact of heat on fishes. Oxygen consumption goes up as temperature rises because the fish begins to live at a faster pace. But unfortunately for the fish, both water in the stream and hemoglobin in the fish's blood can hold less oxygen at elevated temperature. The result--less efficient gill function, breathing rate goes up, and greater energy output is required just to stay even.

Enzyme activity performs all the basic functions of the body. But when temperature is high enough, heat-stimulated enzymes malfunction b exhausting their substrates, or by producing toxic byproducts, or by heat denaturation which, in effect, destroys the enzyme molecule. No one knows why trout die from heat at temperatures that allow carp to thrive. We still ask -- Why do fish die from heat? Is it from enzyme failure? These are crucial questions now being examined by scientists in the Pacific Northwest Water Laboratory at Corvallis, Oregon.

Nutrition and growth are intimately related to temperature so that a temperature rise within limits stimulates more activity, increased food consumption, and accelerated growth. Beyond these limits, the fish's well-being deteriorates rapidly.

The physiologist looks also at reproduction, because this is vital to production of a harvestable fish crop. This function is most sensitive and vulnerable to temperature modification. Similarly, it has been found that many diseases are induced by high temperatures. It appears that heat makes fish more susceptible and the pathogens more prolific and viru lent. Faster breathing also brings pathogens moving over the gills at a greater frequency.

Heat also influences toxicity. Elevated temperatures enhance the action of toxicants, so less is required to affect aquatic life. In rivers that contain a variety of potential toxicants, their synergistic interactions are usually intensified by increased temperature. Such a case was reported recently on the Miramichi River in New Brunswick [6] where zinc and copper weakened the fish and elevated temperature promoted a fish kill caused by disease.

As yet, we do not know the full impact of fluctuating temperature on aquatic life. This may be an important consideration where thermally produced power forms the basic electrical supply with peak power needs met by intermittent use of hydroelectric facilities. It is known that fish acclimate faster to rising than to declining temperatures, so that slugs of cold water from the base of a dam could cause serious harm in a warm river.

With this as a brief background, I wish now to examine specific examples of some of these heat impacts on fishes.

To illustrate the effect of a range of constant temperatures on the reproductive potential, one can use a minnow that is widely distributed in the United States. The fathead minnow (Fig. 3) is an important food source for sport and commercial fishes. Observations show that a constant temperature of 79°F, as compared to 72°F, resulted in a 25% loss in reproductive capacity. At 86°F, reproduction was almost nil. A temperature of 92°F would cause no mortality but would nonetheless eliminate the species because reproduction would be inhibited. This illustrates the great sensitivity of the reproductive stage.

Scientists at the Pacific Northwest Water Laboratory currently are investigating the survival, fertility, and condition of adult salmon that were forced to make a simulated spawning migration at elevated temperatures. Neither cohos nor sockeye survived 72°F for two weeks, and relatively few survived 68° for one month. The resulting influences on fertility among the survivors is unknown at this time. Finally, the condition of fish held at 50°F was judged far superior to that of fish held at 62°F. For example, both male and female sockeye in colder water lost about 8% of their body weight, but at 62°F males lost about 10.5% and females lost about 13.2%.

The National Water Quality Laboratory at Duluth has examined the effect of temperature on the growth rate of the white sucker, a commercially important fish in the Midwest. As shown in Fig. 4, rising temperature has a beneficial effect up to a point. Beyond that point, adverse effects show up rapidly. From 50°F to 81°F, there is pronounced increase in the growth of the suckers. When the temperature exceeds 81°F, growth is reduced. At 86°F, it is only one-seventh of that occurring at 81°F. Even worse, a temperature of 90°F will kill this fish in a 96-hour period! It is important to note that the best temperature for growth is very close to the lethal temperature. One, two, or three degrees may determine the difference between high production and complete elimination of a fish population.

All fishes are not alike; species vary in the temperature at which they do best. Fig. 5 shows this characteristic for three species -- largemouth bass, northern pike, and brook trout. The temperature providing best growth increases from 59°F for the brook trout, to 70°F for the northern pike, to 81°F for the largemouth bass. This emphasizes the principle that the best temperature and also the maximum permissible temperature depend on the species that are being considered. If a brook trout stream is warmed to 81°F, its temperature would be suitable as a largemouth bass stream. The trout would be killed, pike would be in an undesirable temperature range, but largemouth bass would be at their optimal temperature environment. This emphasizes the significance of temperature in determining whether a given river supports cold water or warm water species of fish.

I call your attention next to a theoretical consideration of the way in which heat input can shorten the miles of stream suitable for habitation by salmonids (Fig. 6). This chart was prepared by the National Water Quality Laboratory at Duluth. It shows a situation in which the effect of added heat does not occur at the point of discharge but, instead, at some point many miles downstream. The stream represented here is cc. considering the climate in which it exists, and usually it is fed by springs or snow melt. Many trout and salmon streams are like this. They naturally warm up progressively downstream without any artificial heat addition. The lower curve of the graph shows the natural temperature pattern that would exist from headwaters to mouth if no heat were added. At 100 miles downstream, the temperature naturally exceeds the limit for trout. If heat is added at a point 17 miles below the headwaters, sufficient to raise the stream temperature 2°F, the stream is not harmed at that point for the production of trout. But downstream the temperature reaches the limit for trout sooner, at approximately 83 miles. As a result, the lower 17 miles of the stream are unfit for trout production even though the heat was added 60 miles upstream. If the heat input upstream raises the temperature 5°F rather than 2°F, destruction of trout habitat extends farther upstream. The upper line in the graph shows that there has now been a loss of 42 miles of trout waters as a result of upstream heat addition.

Not cited specifically in this example is one of the most insidious problems of thermal pollution. It is the fact that small increases in temperature, while they may not kill the desirable cold water fishes, can foster the welfare and successful competition of warm water fish. In most trout streams, warm water fishes do not reproduce because the numbe of degree days is not sufficient for maturation of the gonads. Relatively small changes can meet such needs and allow their reproductive proliferation. There then follows a population shift from desirable cold water fishes to less desirable warm water ones. The latter can also serve as a reservoir of diseases that can have devastating effects on trout and salmon.

Potential Uses of Heat

After calling attention to these many ecological implications of thermal pollution, it is only fitting that I terminate these remarks in some more optimistic tone. To do so, I wish to simply enumerate some of the possibilities now considered for beneficial uses of waste heat.

In the United States -- in fact, right here in Oregon -- studies supported by the Eugene Water and Electric Board are to demonstrate that warm water can stimulate and enhance plant growth and protect fruit trees from killing frost. The Pacific Power and Light Company also is supporting work at Oregon State University to determine if growing seasons can be lengthened and crop yields increased by warming the soil.

In Wisconsin, the Department of Natural Resources and the Wisconsin Electric Power Company have joined in a program of intensive fish production in heated fish-rearing ponds. This program, to be located at Two Creeks, should be in operation by 1971.

According to scientists at Massachusetts Institute of Technology, a cooling trend in waters along the Maine coast has caused a decline in growth rate of lobsters. Researchers have a plan to use power plant cooling water to warm the water in shoreline coves so lobsters will thrive again. New York State is considering a similar proposal for a site on Long Island near Montauk Point.

The Institute of Marine Science, at the University of Miami, has joined the Florida Power and Light Company in a waste heat use project. The objective is to learn if a heated effluent can be used to raise pink shrimp and pompano.

At Northport, New York, a 10,000 square foot oyster hatchery is being built so that heated water from the Long Island Lighting Company power plant can be used to maintain optimal temperature for oyster spawning and production. Oysters in the heated water are expected to spawn ten months out of the year rather than the normal three or four. As the young oysters grow they will be placed on rafts and moved into Long Island Sound.

In England, Scotland, and Russia there are several additional programs to use waste heat in experimental or commercial production of fish and shellfish.

Finally, at Tapiola, Finland, not far from Helsinki, cooling water from the community power plant is routed through a piping system to business and residential buildings. It provides heating, as needed, 270 days per year.

Conclusion

In conclusion, these are examples of the thermal effects on ecological systems. The planet as a whole is not much affected by man's heat-generating activities. But in the aquatic environment, there is a great potential for destruction through thermal pollution. This can be avoided if we give proper attention to the ecological knowledge now at hand.

LITERATURE CITED

1. "Temperature and Aquatic Life. Laboratory Investigations - Number Tech. Advy. & Investig. Br., Tech. Serv. Prog., FWPCA, U. S. Dept. Int., Cincinnati, Ohio. Dec. 1967.

2. Cole, L.C. "Thermal pollution," BioScience 19, 989-992. Nov. 1969.

3. Krenkel, P.A., E. L. Thackston, and F. L. Parker. "Impoundment and temperature effect on waste assimilation," J. San. Engrg. Div., Proc., Am. Soc. of Civil Engrs., Feb. 1969.

4. "FWPCA Presentations - ORSANCO Engineering Committee," 17th Meeting, Ohio Basin Region, FWPCA, U. S. Dept. Int., Cincinnati, Ohio, Sept. 10, 1969.

5. Trembley, F. J. "Research Project on Effects of Condenser Discharge Water on Aquatic Life," Prog. Report, 1969. The Inst. of Res., Lehigh Univ., 1961.

6. Pippy, J.H.C. and G. M. Hare. "Relationship of river pollution to bacterial infection in salmon (Salmo salar) and suckers (Catastomus commersoni)," Trans. Am. Fish. Soc. 98, 685-690. 1969.