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Scope of Study: This paper presents a study of the effects of water, heated both naturally and industrially, on invertebrate fauna. This report was compiled by reviewing literature present in the Oklahoma State University Library.

Findings and Conclusions: Water, heated both naturally and industrially, greatly limits the number of species that can inhabit it. Even the species present are not abundant. Heating also changes the chemical characteristics of water. This is also detrimental to the invertebrates present. Very little work has been done on hot springs in the last twenty years. Very few field studies have been conducted on effects of industrial thermal pollution.

ADVISER'S APPROVAL ______________________________

A STUDY ON HEATED WATER AND ITS EFFECT ON AQUATIC INVERTEBRATES

By

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CHAPTER I

INTRODUCTION

Water, heated both naturally and industrially, has diverse effects on the invertebrate fauna. The aquatic invertebrates react in varying ways to this heated water. Some organisms escape warmer temperatures by having an egg stage during times when the water is warmest, others move to another area, and still others are killed as a result of exposure to the high water temperature. Death from heat does not necessarily occur during or immediately after exposure, and if deferred, is not evenly distributed through the passing hours. Rather, as the life history develops, death may be restricted mainly to times of greatest physiological activity when there is need for close interaction between crucial processes (Allee, et al., 1949).

Following are the three reasons why a species is prohibited from colonizing warmer waters (Macam, 1963):

a. It is lethal.

b. There is competition. Some organisms are more active at a certain temperature than others which occupy the same niche.

c. The temperature is never low enough to stimulate reproduction.

CHAPTER II

GENERAL PROPERTIES OF HOT SPRINGS

Springs are the aquatic ecologist's natural constant temperature laboratories. Because of the relative constancy of the chemical composition, velocity of water, and temperature in comparison with lakes, rivers, marine environments, and terrestrial communities, springs hold a position of importance as study areas that is out of proportion to their size and number (Odum, 1959).

The constant temperature properties of hot springs affect the immediately surrounding area. Thermal waters deposit geyserite, a silicious sinter, which covers the soil and which apparently decomposes slowly. High temperatures prevail throughout the year in the springs and the immediate area, and allow certain organisms to expand their range. This allows them to exist in regions where they would not otherwise occur. For example, organisms of warmer climates occur in Icelandic hot springs (Odum, 1959). Certain snails found only in warm springs in Europe are believed to be the survivors from a time when the whole continent was much warmer (Macam, 1963). It is apparent that springs have provided refuges for aquatic organisms during geologic periods when climatic changes have occurred (Odum, 1959).

Occurrence of Hot Springs

Hot springs occur in many parts of the world. They are most frequently found in places which show signs of volcanic activity. In practically all areas where active hot springs occur, there are evidences of the vast extent and enormous size of earlier springs now extinct (Brues, 1928). This is apparent because of chalky white or colored deposits produced by calcareous hot springs and distinctive sinter cones and formations resulting from the flow of silicious springs. The temperature and rate of flow vary greatly in the different springs. Geysers emit superheated water which gives off a great amount of steam. Others contain only boiling water. The majority of hot springs are hot, warm, tepid, or can only be recognized as hot springs by the use of a thermometer.

The United States has several states in which hot springs are located. A few springs of very moderate temperature exist in New York, Virginia, and Arkansas. The most extensive range of hot springs and those exhibiting really high temperatures are located in parts of California, Colorado, New Mexico, Utah, Nevada, and Yellowstone Park, Wyoming. The latter contains the largest and most varied hot springs in the world. A continuous series of springs with respect to temperatures can be found in Yellowstone Park.

Origin of Hot Springs

Springs having a higher mean annual temperature than the ground from which they arise must in a hydrographic sense be designated as thermal waters (Ruttner, 1964). They, like other springs, originate either from the vadose water derived from the earth's surface, which as a result of geological stratification reaches great depths and there becomes warmed, or from juvenile water, which originates in the interior of the earth and comes to the surface in volcanic regions or along thermal fissures. Juvenile water is usually laden with gases and salts. From an ecological standpoint we include as thermal waters those biotopes in which the limiting and selecting influence of high water temperature is clearly apparent on the composition of the biocoenose (Ruttner, 1964). As a rule this is the case at temperatures near 30 degrees centigrade. In general, however, 25 degrees centigrade to 30 degrees centigrade seems to be the dividing line between a rich fauna at lower temperatures and a poor fauna at higher temperatures (Odum, 1959).

Temperature

In hot springs, the most obvious factor affecting life would be the high temperature of the water; therefore, this would immediately attract the attention of the biologist. Organisms which live in water at certain temperatures have been classified as follows (Brues, 1924):

a. hypothermophilous--below 15 degrees centigrade (58 degrees Fahrenheit)

b. mesothermophilous--15 to 30 degrees centigrade (58 to 86 degrees Fahrenheit)

c. euthermophilous--30 degrees centigrade and up (86 degrees Fahrenheit and up)

When exploring the surface temperature of hot springs with a radiometer, Bates (1961) noticed at certain places that large temperature differences may exist within a very short horizontal displacement. At first he thought this to be an error, but soon he discovered that it was a fundamental property of a very interesting phenomenon involving the surface layer. Most of the hot springs had a thin film on the surface which extended out a distance from the edge determined by the convection currents within the pool and the action of wind stress on the surface. These films were judged to be monomolecular.

This means considerable care must be exercised when taking temperatures at which organisms are collected in hot springs. There can be a great difference in temperature within a few inches.

Oxygen

Another common characteristic of thermal water is the small amount of oxygen present. This is particularly true for those waters which emerge from the earth at a very high temperature. This lack of oxygen further handicaps the inhabitants of hot springs except those organisms which secure their oxygen from the atmosphere above the surface of the water.

In the overflow from geysers and in pools rapidly supplied by water from boiling springs the process of cooling to temperatures compatible with animal life takes place quickly and there is little opportunity for atmospheric air to be dissolved by the water (Brues, 1927).

Salts and Gases

Hot springs are also characterized by large quantities of dissolved salts and gases (Brues, 1927). The nature of the salts is naturally dissimilar in different places since it is dependent upon the constitution of the rocks with which the heated water has been in contact. The salts most frequently present are calcium carbonate, silica dissolved in the presence of sodium carbonate, sodium sulphate, sodium chloride and gypsum, with occasionally appreciable amounts of arsenical materials. Gases frequently present are carbon dioxide, hydrogen sulfide, and sulphur dioxide. The addition of salts causes alkaline conditions while the dissolving of hydrogen sulfide and sulphur dioxide causes an acidic environment. Alkaline springs are the most common type. Brues (1932) states differences in salinity are of lesser importance than temperature in determining the composition of the thermal fauna.

Suspended Materials

Occasionally, noticeable amounts of finely divided mineral materials are suspended in pools of tepid water. Some of these pools are ebullient without much flow. The water in these pools becomes thick and pasty resulting in mud geysers or "paint-pots."

Relationships of Thermal Fauna

It is evident that freshwater animals which have been able to adjust to the highly saline water of brackish ponds or of the ocean are those that generally occur in hot springs, although no marine forms are present in hot springs (Brues, 1927). There is also a great similarity between these two faunae and the littoral zone fauna of the seas, because littoral animals must also be able to withstand high temperatures. It is apparent that a great majority of animals which occur in thermal waters have close relatives which live in saline, alkaline, brackish water or even in the sea. The only similarity among all these situations is the considerable amount of soluble salts in the water. From this it seems reasonably evident that fresh water groups of animals that have developed species adapted to thermal waters have done so through the ability to adjust their metabolism to the increased osmotic pressure of the medium (Brues, 1927).

Life in the Hot Springs

In 1796 Saussure, in France, noticed both plants and animals living in hot water at temperatures well above that in water ordinarily populated by living organisms. Since then other investigators all over the world have done intensive research on this phenomenon.

Certain plants occur in water of much higher temperatures than those at which any forms of animal life are able to exist. Two forms of blue-green algae, Phormidium bijahense and Oscillaria filiformis apparently hold the record for multicellular plants (Allee, et al., 1949). They live in the hot springs of Yellowstone Park at a temperature of 85.2 degrees centigrade. These algae seem to have special morphological and cytological adjustments which allow them to function at this temperature. Living bacteria have been found in even hotter waters at 88 degrees centigrade (Allee, et al, 1949).

The temperature requirements for animals are much more exacting than those for lower plants (Brues, 1927). Practically all groups of animals that are represented abundantly in fresh water contain a few species known to inhabit thermal waters. Unlike cold springs, there does not seem to be any typical genera or species in hot springs, nor are hot spring animals ever abundant (Odum, 1959). The protozoans are the most resistant of all animals. Rhizopods and flagellates have been found in Italian hot springs at

54.5 degrees centigrade. Beetles are among the most characteristic metazoan inhabitants. Many species of beetles have been reported from a variety of hot springs in western states. Dipteran larvae also appear to be fairly common inhabitants of hot springs. Chironomidae are especially common. Some other dipterans also found are culicids, hemipterans, brine flies, and stratiomyiids. These insects have been collected from springs with temperatures between 32 degrees centigrade and 51 degrees centigrade. A few nematodes and rotifers have been found in water as hot as 60 degrees centigrade. Brues (1939) regards 50 to 52 degrees centigrade as the highest temperatures compatible with active animal life. Encysted animals and plant seeds resist much higher temperatures. An examination of the temperatures at which animals have been taken in thermal waters indicates that the majority of heat tolerant animals live in water below 40 degrees centigrade (Allee, et al., 1949). As the temperature departs more and more from the usual optimum, the number of species that can tolerate such a temperature becomes reduced. This is a phase of a much more general principle: Wherever and whenever conditions approach a pessimum, the biota becomes impoverished, the more so, the closer the approach to the limits of toleration (Allee, et al., 1949).

The fauna of North American hot springs is more completely known than that of any other part of the world

(Brues, 1939). Table I presents a listing of the invertebrates which have been found in North American hot springs.

Temperature Distribution of Common Inhabitants

The chironomids are the most common organisms found in hot springs. They occur in the mud beneath the water, and have been found at temperatures up to 124 degrees Fahrenheit (Brues, 1939). Chironomids have the respiratory pigment hemoglobin present in their system. Hemoglobin is not rare in lower animals and is found chiefly in mud dwellers (van der Heyde, 1922). Leitch (1916) studied the role of hemoglobin in midges. He found the function of hemoglobin consists in making available, by its power of binding oxygen chemically, a quantity of oxygen sufficient for the needs of the animal at oxygen tensions so low that the necessary amount is not supplied by physical solution. He also showed that the actual storage capacity for oxygen of the hemoglobin in larvae of *Chironomus* is sufficient for only a few minutes of anaerobic life. Thus hemoglobin is characteristic of many mud-dwelling invertebrates that live where oxygen is present in only small amounts.

The Stratiomyiidae are the next most common dipteran inhabitants of hot springs. In 1882 a man in Gunnison County, Colorado, reported that he found some stratiomyiids living in a hot spring at a temperature of 157 degrees Fahrenheit (Packard, 1882). However, none have been reported at this high temperature since then, so there was undoubtedly

TABLE I

INVERTEBRATES LIVING IN HOT SPRINGS OF NORTH AMERICA

CLASS: ARACHNIDA
- Order: Acarina

CLASS: CRUSTACEA
- Order: Amphipoda
  - Isopoda
  - Ostracoda

CLASS: INSECTA
- Order: Coleoptera
  - Family: Hydrophilidae
    - Dytiscidae
    - Helmidae
    - Heteroceridae
    - Gyrinidae
    - Haliplidae

- Order: Diptera
  - Family: Chironomidae (including Ceratopogonidae)
    - Stratiomyiidae
    - Culicidae
    - Tabanidae
    - Ephydridae
    - Simullidae
    - Syrphidae

- Order: Hemiptera
  - Family: Corixidae
    - Notonectidae
    - Gerridae
    - Naucoridae
    - Nepidae
    - Belastomatidae

- Order: Odonata
  - Family: Agrionidae
    - Libulliidae

- Order: Trichoptera
  - Family: Limnophilidae

CLASS: MOLLUSCA
- Order: Gastropoda

an error in the taking of the temperature. The stratiomyiid larvae are known to dwell among the algae in the cooler edges of the springs. Brues (1939) discounts, pending more evidence, certain reports that larvae of brine flies (Ephydridae) live at temperatures of 55 degrees centigrade and even at 65 degrees centigrade. The Coleoptera occur more generally and abundantly in thermal waters than any other group of insects (Brues, 1927). Some species appear to be restricted to warm springs. Some species have been found living at temperatures of 115 degrees Fahrenheit.

Odonatans are rarely found in waters over 40 degrees centigrade. Several species of Acarina live in water above 40 degrees centigrade, and one species is found to be very abundant at 50.8 degrees centigrade. Gammarus limnaeus, an amphipod, is widely distributed in cold water as well as being found in thermal waters. Nine species of ostracods are found at temperatures greater than 40 degrees centigrade and one species is common at 50 degrees centigrade. Mosquitos are common in "paint-pots" and caddisfly larvae occur in sulphurous ponds. Snails have been collected in springs at temperatures up to 96 degrees Fahrenheit.

Effects of Thermal Springs on Streams

Animals from streams are less resistant to heat than are related animals from small ponds (Allee, et al., 1949). Such differential resistance is probably a result of natural selection. One reason for the lack of more data concerning the point at which heat deaths occur is that in the lower range of lethal temperatures, the effect of heat is a function of the duration of exposure as well as the absolute temperature (Allee, et al., 1949).

In the case of streams, the temperature of two points only a few centimeters distant from one another may differ 10 to 15 degrees centigrade because of currents imperceptible except to the thermometer. This is likely to be the case in springs or overflows into which colder currents come from side streams, whether these be of thermal or cold waters.

In an Austrian stream temperature increases suddenly by about 5 degrees centigrade where water from a hot spring comes in. There are marked changes in the fauna. Various Plecoptera disappear and two species of snails become suddenly abundant (Macam, 1963). Plecoptera are associated with cold water, but there is no explanation of why the snails become so abundant.

The Firehole River flows along a fault in a rhyolite lava plateau and through a series of centers of hydrothermal activity. The runoff water from the hot springs flows into the river. A study (Armitage, 1958) was conducted to determine the effects on invertebrates living in the river. Two other rivers were also surveyed to gather more information about the various factors influencing the ecology of the bottom fauna. One of these rivers had hot springs flowing into it and the other one did not.

All samples were taken from riffles. It was found that the runoff water from the hot springs greatly changes the physical and chemical characteristics of the river, therefore affecting the bottom fauna. This change was evident in the progressive downstream increase in temperature, pH, and alkalinity. The average yearly standing crop of the Firestone River was positively correlated with temperature and bicarbonate alkalinity, the latter being highly significant.

From reviewing the literature it appears that very little work has been done on the fauna of hot springs in the last twenty years. Also, very little is known about the effects of hot springs on rivers and streams.

CHAPTER III

HEATED EFFLUENTS

Hot water is produced by industries which use water for cooling purposes. The water used is usually river water which is pumped through the cooling system, and raised to a higher temperature during part of its journey. At present the majority of heated effluents are produced by industries and hydro-electric power stations.

Heat declines as the water goes downstream from the point of discharge of the effluent, partly because of dilution and partly because of loss to the atmosphere and river bed. The rate of such heat loss depends on purely physical factors as turbulence and wind speed, but primarily it depends on the temperature difference between the water and its surroundings (Hynes, 1960). The rate of heat loss declines as the temperature falls. Because of this a temperature difference may persist for many miles.

The biological effects of discharge of clean, hot effluents into rivers and streams depend on how much the temperature of the water is raised. If the increase is small, there is probably only a general speeding up of biological processes in the water. If there is a steep rise in temperature, 5 to 10 degrees centigrade, there will be clear biological consequences. If temperatures of about 40 degrees centigrade are exceeded, most normal river organisms will be eliminated. They will reappear downstream only as the temperature falls.

If the original water is polluted, trouble is experienced because of the growth of bacteria. To kill the bacteria the water is often chlorinated. Chlorine combines readily with organic matter in water. However, chlorination can produce toxic effluents even if no free chlorine remains in the water. If thiocyanates are present in the effluents, chlorine will combine with them to form toxic compounds. Also heating increases the biochemical oxygen demand by killing bacteria, small plants, and animals in the water, and turning them into dead organic matter. This can be caused by heat or chlorination.

Heating of a polluted river also has profound biological effects. It can stimulate the growth of sewage fungus and speed up all other biological activities. It increases the toxicity of the poisons that are already present. Also, the greater rate of oxidation results in higher production of carbon dioxide, which itself raises the lowest oxygen content which organisms can tolerate. The final effluent can be more polluting than was the water at the intake.

There is very little information available on the temperature tolerances of freshwater animals living in heated effluents. Very few field studies have been undertaken to determine the effect of heated effluents on natural communities.

Mann (1958) reported the occurrence of a tropical tubificid Branchyura sowerbyi in the Thames, at a point where the water is warmed up to 25 degrees centigrade by a power station effluent: previously this species was known in England only from hot houses. Similarly, Naylor (Hynes, 1960) recorded a number of exotic marine animals from an artificially warmed dock in Swansea. Two of the species, a crab and a barnacle, are only able to survive in Britain under the conditions produced by heated effluents.

Trembly (1956) investigated the effect of condenser discharge water upon aquatic life in the Delaware River. The discharge water was 20 to 25 degrees Fahrenheit above the temperature of the normal river water. He found that the heated water contained less oxygen than the normal river water, but was never low enough to restrict aquatic life. Aquatic invertebrates found living in the warm water in fairly good abundance were caddisfly larvae, limpets, two species of snails, and midges, in that order. These were also abundant in normal river water. The warm water completely restricted the range of tardigrades.

Coutant (1961) also investigated the same area of the Delaware River that Trembly had. Coutant collected only riffle samples of benthic macroinvertebrates. He found that the heated waters greatly affected the invertebrate populations during the summer and fall months. There was an indication that for some organisms the annual cycles of abundance are shifted out of their normal seasonal positions. Chironomids and pond snails were found to be very tolerant of high temperatures. The data suggested a tolerance limit close to 90 degrees Fahrenheit. No life was found at temperatures of 105 to 100 degrees Fahrenheit.

The writer has conducted research on the effect of heated effluents from a hydro-electric power station. Midges were found to be the most tolerant of warm water. As the water cooled, caddisfly larvae became numerous, along with midges. Also found were numerous *Branchyura sowerbyi*, which have been used as indicators of warm water. This species is considered to be rare in Oklahoma.

CHAPTER IV

SUMMARY

Hot springs furnish the warmest environments known to be inhabited by active organisms. Spring communities are characterized by relatively small numbers of species. In hot springs this is due to relatively few organisms being adapted physiologically to high temperatures and high salinities. Springs are further simplified by the absence of plankton (Odum, 1959).

Heated effluents can cause great changes in the invertebrate fauna of rivers and streams, resulting in the elimination of many species present in normal rivers and streams. The tolerance limit for life appears to be about 90 degrees Fahrenheit. Above this, invertebrate life has not been found in rivers and streams. To this date, very vew studies have been undertaken on this problem of thermal pollution.

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