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Biota and Biological Principles of the Aquatic Environment

Biota and Biological Principles of the Aquatic Environment

Edited by Phillip E. Greeson

Briefing Papers on Water Quality

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FOREWORD

In August 1974, the Water Resources Division of the U. S. Geological Survey introduced the first of a series of briefing papers that were designed to increase the understanding of its employees of the significance of various aspects of water quality. Numerous briefing papers have been prepared under the direction of the Quality of Water Branch. Other papers will be prepared as the need arises. Each paper addresses a separate topic and is written in a nontechnical, easy-to-understand manner for distribution within the organization.

Because of the favorable reception that the papers have received and their apparent effectiveness in accomplishing the objective stated above, it would appear that their wider distribution would serve a useful purpose. It is hoped that a wide range of persons, including those interested in the quality of our Nation's water resources but who have little or no technical training, will find value in reading the papers. Furthermore, it is hoped that the papers will be suitable for supplemental reading in secondary education programs and in beginning college-level courses.

The U.S. Geological Survey plans to publish several U.S. Geological Survey Circulars that contain compilations of briefing papers on particular aspects of water quality. This first Circular contains eight papers describing selected groups of aquatic biota and biological principles of the aquatic environment.

Philip Cohen
Chief Hydrologist

CONTENTS

ILLUSTRATIONS

TABLE

BRIEFING PAPERS ON WATER QUALITY

Biota and Biological Principles of the Aquatic Environment

Edited by Phillip E. Greeson

ABSTRACT

This is the first of several compilations of briefing papers on water quality prepared by the U.S. Geological Survey. Each briefing paper is prepared in a simple, nontechnical, easy-to-understand manner. This U.S. Geological Survey Circular contains papers on selected biota and biological principles of the aquatic environment. Briefing papers are included on "Why biology in water-quality studies?," "Stream biology," "Phytoplankton," "Periphyton," "Drift organisms in streams," "Family Chironomidae (Diptera)," "Influences of water temperature on aquatic biota," and "Stream channelization: Effects on stream fauna."

Why Biology in Water-Quality Studies?

By Phillip E. Greeson

ABSTRACT

This paper describes the relationship between the limits of tolerance of aquatic organisms for environmental factors. Because the tolerance limits of individual organisms vary, the flora and fauna of streams and lakes are indicators of environmental extremes and integrators of environmental quality. The paper concludes that biological, physical, and chemical data supplement each other to provide converging lines of evidence for defining water quality. The data are not mutually exclusive.

WHY BIOLOGY ?

Within the past 10–15 years, the field of water quality has been expanded rapidly to include a broadened interest in aquatic biology. Many investigators have become exposed to a new technical vocabulary. Terms such as periphyton, phytoplankton, artificial substrates, benthic invertebrates, biomass, biological indices, and so on are appearing more frequently in the technical literature. All of these terms relate to the biological activities of water-quality investigations.

We may well be pondering the question, "Why biology in water-quality studies?" Let us pursue the question. Without attempting to delve deeply into theoretical aspects of aquatic biology, it will suffice to look very briefly at some recent events and aquatic ecological principles.

The Water Pollution Control Act Amendments of 1972 (Public Law 92–500), updated by the Clean Water Act of 1977 (Public Law 95–219), were enacted for the purposes of assuring supplies of water suitable for domestic uses, agricultural uses such as irrigation and stock watering, power generation, and industrial processes; restoring and maintaining aesthetically pleasant waters for recreation; and ensuring water of the quality needed for the survival, growth, and reproduction of freshwater and marine life.

A careful examination of these purposes reveals that the maintenance of high-quality waters is to provide conditions suitable for living things, including man, and are thus biologically significant. As we look deeper into the cause and effects of water quality, we find more and more aspects that fall within the realm of aquatic biology.

For many years, the investigations of water quality have been approached in narrow and parochial ways. The reasons are many and, perhaps, justified. For many years, water-quality studies consisted solely of the collection of selected physical and chemical data and interpretation of those data.

Although physical and chemical measurements provide information for evaluating water quality, there are limitations to evaluation based exclusively on these variables. Physical and chemical determinations, for example, represent, for the most part, conditions only at the time of sampling. Chemicals that influence water quality are numerous, vary widely in concentration, form complex compounds, and interact with the physical properties in numerous ways to produce a wide range of effects; therefore, dependence upon this type of information alone may be inadequate for fully characterizing water quality. Aquatic organisms, on the other hand, respond continually to the environment, reflecting in their numbers and kinds, the interactions of all chemical, physical, and biological factors.

To calculate the average value of an environmental variable (for example, a nutrient) or to sample some aspect of water quality at a point in time is not a measure of the suitability of an environment for sustaining life. It is the magnitude and duration of the extremes of environmental conditions that are important. Aquatic organisms, by virtue of the requirements for their existence, represent those extremes.

ENVIRONMENTAL REQUIREMENTS

Every organism, whether aquatic or terrestrial, requires certain physical and chemical conditions for its existence. If any condition falls below or exceeds a certain point, the organism dies or moves away, and there is a change in the number and kinds of organisms remaining. For example, one would not expect to find a tropical angelfish in an Arctic stream because the water is too cold, nor to find a largemouth bass in the salty ocean because the dissolved solids content is too high. All the organisms have ecological minimum and maximum limits, with a range in between which represents the "limits of tolerance."

The limits of tolerance are specific for every organism. A condition that is suitable for one organism may be entirely unsuitable for another. Similarly, the lower limit of tolerance for one organism may be the upper limit of tolerance for another. Figure 1 is a diagrammatic representation of variations in tolerance limits.

In the figure, organism *A* cannot exist under the same conditions as organism *C*. Organism *B*, however, could exist with either organism *A* or organism *C*. The limits of tolerance for organism *B* are widely separated; therefore, its range of tolerance is greater than that for organism *A* whose limits of tolerance are relatively close.

Because the tolerance limits of individual organisms vary widely, the flora and fauna of streams and lakes are indicators of environmental extremes and integrators of environmental quality. In other words, a knowledge of the numbers and kinds of organisms in an aquatic community is a measure of local water-quality conditions.

COMPONENTS OF THE BIOLOGICAL COMMUNITY

Ideally, all segments of an aquatic community should be defined in the evaluation of water quality; but, because of limitations in time, expertise, and budgets, biological studies usually are limited to the study of a few major groups of aquatic organisms. Five groups of organisms – bacteria, fish, plankton, periphyton, and benthic invertebrates – traditionally have been studied as indicators of water-quality conditions. The bacteria serves as indicators of fecal contamination and the presence of pathogenic organisms. Fish are somewhat unsuitable for water-quality studies because their superior mobility enables them to cover great distances and, therefore, to avoid many undesirable conditions.

Plankton, because they float passively with the currents, are indicative of quality conditions of the mass of water in which they are contained. Estimation of the plankton population indicates, in part, the nutrient-supplying capability of that mass of water. A similar definition possibly could be de-

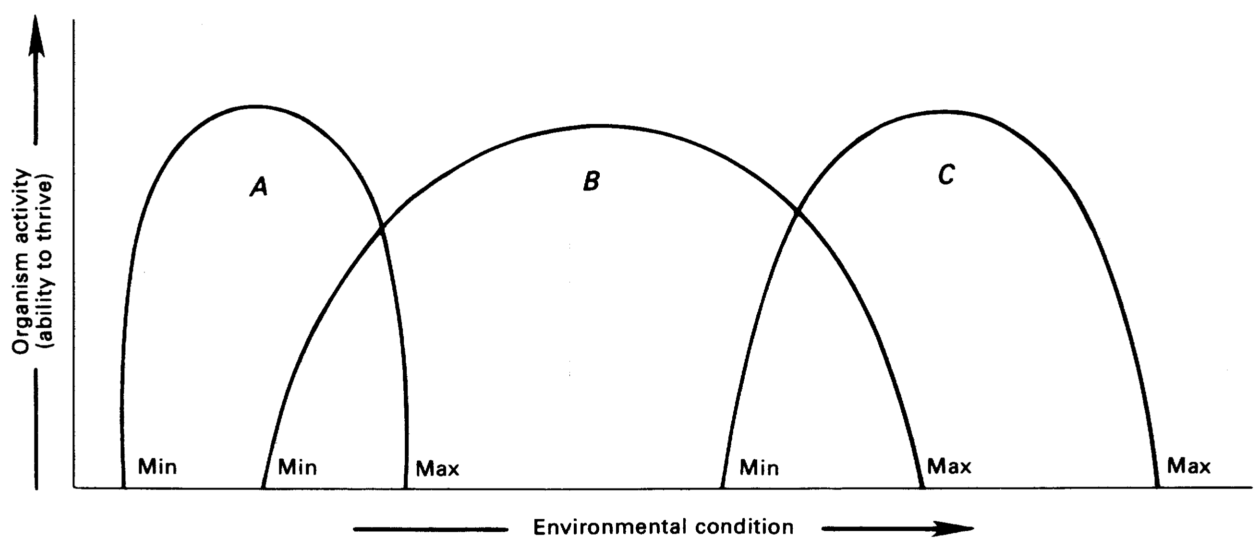

FIGURE 1. – Comparison of tolerance limits for organisms *A, B,* and *C.*

rived by chemically analyzing the water for all known nutrients, a formidable and expensive task. Periphyton also provide an indication of the nutrient supply in water; and, in addition, because of their stationary or sessile existence, they represent an integration of the chemical and physical conditions of water passing the point of their location.

Benthic invertebrates are excellent indicators of stream conditions, primarily because they are restricted to the area in which they are found. The various kinds of invertebrates are somewhat well-known for their limits of tolerance, their life histories are usually sufficiently long to respond to environmental changes, and the presence or absence of particular groups is indicative of quality. Benthic invertebrates, because of their varying environmental requirements, form communities characteristic or associated with particular chemical and physical conditions. Biologists now know that the presence in water of immature insects, such as mayflies, caddisflies, and stoneflies, and certain mollusks and crayfish usually characterize relatively "clean" water conditions. On the other hand, the presence of sludge-worms, midges, air-breathing snails, and aquatic earthworms is indicative of the presence of oxygen-consuming organic materials. It is significant to recognize that the number of different kinds of invertebrate organisms present, rather than the numbers of individuals of a particular kind, is of greater importance as an indicator of quality conditions.

The complete absence of aquatic biota in an otherwise clean-appearing stream may indicate the presence of toxic substances. Sublethal levels of toxicants may be detected by analyzing the flesh of organisms, because the toxicants can be concentrated through food chains.

Surveys of aquatic organisms often result in extensive lists of latinized names of species and numbers of individuals per species. Needless to say, this type of information is in fact one measure of water quality, in just the same manner as a list of the concentrations of dissolved inorganic substances is another measure of water quality. The interpretation of aquatic biological data, however, generally rests with the trained and experienced biologist. Such a condition will gradually change as specialists in other disciplines become familiar with the basic concepts and principles of aquatic ecology.

One of many tools used to simplify the analysis and interpretation of biological data is the diversity index. The diversity index is the ratio of the number of species of taxa to some other important value, usually the total number of organisms in a sample of a community. It is a measure of the evenness of distribution of individuals within the community.

The concept of the diversity index is based on the assumption that good quality waters generally have higher diversity values because the benthic community contains many species of relatively equal abundance. Poor-quality waters generally have low diversity values because many pollution-sensitive species are eliminated from the community and a few tolerant organisms thrive in the absence of competition and the presence of an abundant food supply.

THE ANSWER

It is important to recognize that biological data do not replace chemical and physical data any more than chemical and physical data replace biological data. They provide converging lines of evidence over time that supplement one another; they are not mutually exclusive.

To answer the question, "Why biology in water-quality studies?," one must correctly say that aquatic biology is one important aspect of water quality.

Stream Biology

By Keith V. Slack

ABSTRACT

The ecosystem consists of the living community of organisms interacting with the physical and chemical environments. The organisms in the ecosystem have different roles – there are the producers, consumers, and decomposers. The types of organisms in a stream vary with the physical and chemical environments, both natural conditions, and from the effects of different types of pollution.

INTRODUCTION

Biology has a unique role in water quality. Not only is biology a tool for water-quality evaluation, but it is a focus for water-quality concern. Many water-quality standards are based on the conditions that groups of aquatic organisms – usually fishes – must have in order to survive. These life requirements are rather stringent. In fact, if water quality is suitable for a natural varied population of aquatic plants and animals, it also will be suitable for almost all other beneficial uses of the water by man.

To understand the significance of aquatic organisms in water-quality investigations, the following must be considered: (1) what the organisms look like, (2) where they live, (3) how they interact with one another and with their surroundings, and (4) how they relate to water quality. The following brief discussion is intended to provide that background.

THE ECOSYSTEM CONCEPT

Everyone is familiar with at least one group of aquatic organisms, the fishes. However, unless one is an avid fisherman, he may not have given much thought to the fact that fish must have food to live, grow, and reproduce. Even the dedicated angler may not have considered the factors responsible for the production of the food to support a viable fish population.

The fact is that many different animals and plants live in most streams, but the assemblage of aquatic life is not a haphazard collection of species. The plants and animals that inhabit a reach of river comprise a functioning or interacting unit known as a biotic community.

All living things require energy to carry out life functions which include growth, reproduction,and, in some organisms, movement. Plants are the primary producers of new organic material in the aquatic ecosystem. Using the energy from sunlight in the process of photosynthesis, green plants assimilate inorganic substances from their surroundings and produce organic matter. The inorganic substances used by plants are commonly called nutrients. Presently some 40 to 50 essential plant nutrients are known. However, only two of the so-called major nutrients, nitrogen and phosphorus, commonly are identified as such in water-quality studies. The inorganic nutrients are derived from the rocks and soil of the drainage basin, from fertilizers, and from wastes discharged into the streams by man.

Animals, unlike plants, cannot manufacture their own food from inorganic materials. Instead, animals must obtain their energy by consuming organic matter such as other animals or plants, living or dead. The energy in the food consumed by the animals is released in the process of respiration. The organic matter (food) utilized by aquatic animals may be produced in the stream itself (for example, algae or other aquatic animals) or it may be introduced from the drainage basin (for example, tree leaves or domestic sewage). Some aquatic animals are vegetarians, feeding directly on plants. These animals, often called herbivores, represent the primary consumers because they subsist on the products of primary production. Another group of animals, called detritivores, feed on organic detritus or dead organic matter. A third large group of animals, called carnivores, feed on other animals, including representatives of the first two groups. The carnivores are the secondary consumers, and higher orders of consumers can be identified. For example, in the food chain of:

algae → mayfly → dragonfly → fish

the relationships can be expressed as

primary producer
↓
primary consumer
↓
secondary consumer
↓
tertiary consumer.

The detritus feeders enter the picture to consume the dead bodies or parts of any of the other organisms.

A third important group of aquatic organisms consists of the bacteria and fungi which decompose or break dead organic matter into its inorganic chemical components, which can again enter the cycle through photosynthesis and plant assimilation.

The interaction of the living community and the physical and chemical environment makes up an ecosystem. The scientific study of the relations of organisms or groups of organisms with their environment is call ecology.

STREAM HABITATS

Stream channels may be divided conveniently into two general types: (1) those with eroding, generally firm beds, and (2) those with depositing, generally soft beds. In many streams, these types alternate in the familiar swift-water riffles and the quiet pools. Aquatic communities are quite different in the two situations (fig. 2). The communities of pools resemble those of ponds or lakes. Many of the animals of pools burrow into the soft sediment for protection and food. The animals of the hard-bottom riffles, however, are more specialized and adapted in various ways to life in swift currents. Many of the riffle-dwelling animals have claws, hooks, or suckers by which they cling to the stream bottom to avoid being swept away. Other riffle inhabitants are adapted to their environment by a flattened and streamlined shape or by behavior pattern that result in their avoiding the current by hiding under rocks or among algae or other plants. The animals that live in or on the stream bottom are called benthic animals.

TYPES OF STREAM ORGANISMS

PLANTS

An unpolluted perennial stream supports a suprisingly wide range of aquatic life, and the type and variety of life changes from headwaters to mouth. The speed of the current, the type of bottom sediment, and the amount of light are among the most important factors that influenced the character of life in a stream, but temperature and water chemistry also are important.

Since plants are the basis on which all animal life depends for food and often for shelter, the myriad of kinds of plants can be placed into three broad categories for description. First are those forms that live attached to solid objects in the water (figs. 3*A*, *B*). They do not have roots in the usual sense. These are the algae and mosses that are especially noticeable in small rocky streams. In very swift currents, the plant structure is either cushion-shaped or with a strong flexible stem. In places where the bed is unstable, this group of plants does not occur, unless other firm surfaces are present. The term periphyton is used for the entire community of attached algae and other microscopic organisms that are attached to or live upon submerged objects.

In the second category are the aquatic plants with roots, usually growing in the streambed, but sometimes floating (fig. 3*C*). These plants include the water lily, the floating water hyacinth and water cress, and many bottom-rooted plants often collectively called "water weeds" or macrophytes. The larger plants provide cover and food for aquatic animals, oxygen for the water, and most importantly, surfaces for attachment of uncounted millions of algae which comprise the periphyton. These microscopic plants of the periphyton are a major food source for animals and probably are more important than the rooted plants as oxygenators of the water.

In a third category of plants are the phytoplankton, microscopic algae that drift freely in the water. In smaller streams, these planktonic forms usually are fragments of the attached algae that are scoured accidentally from the rocks and then carried along with the flowing water. Further downstream, the plankton may contain lake or pond species of algae derived from bodies of standing water in the drainage basin or from quiet backwaters. In general, plankton is not as ecologically important in streams as it is in lakes.

A notable feature of these plant groups is that they vary in abundance at different places in a given reach of channel and at different seasons. In most streams, there is a minimum of algae in winter and usually maximums in the spring and autumn.

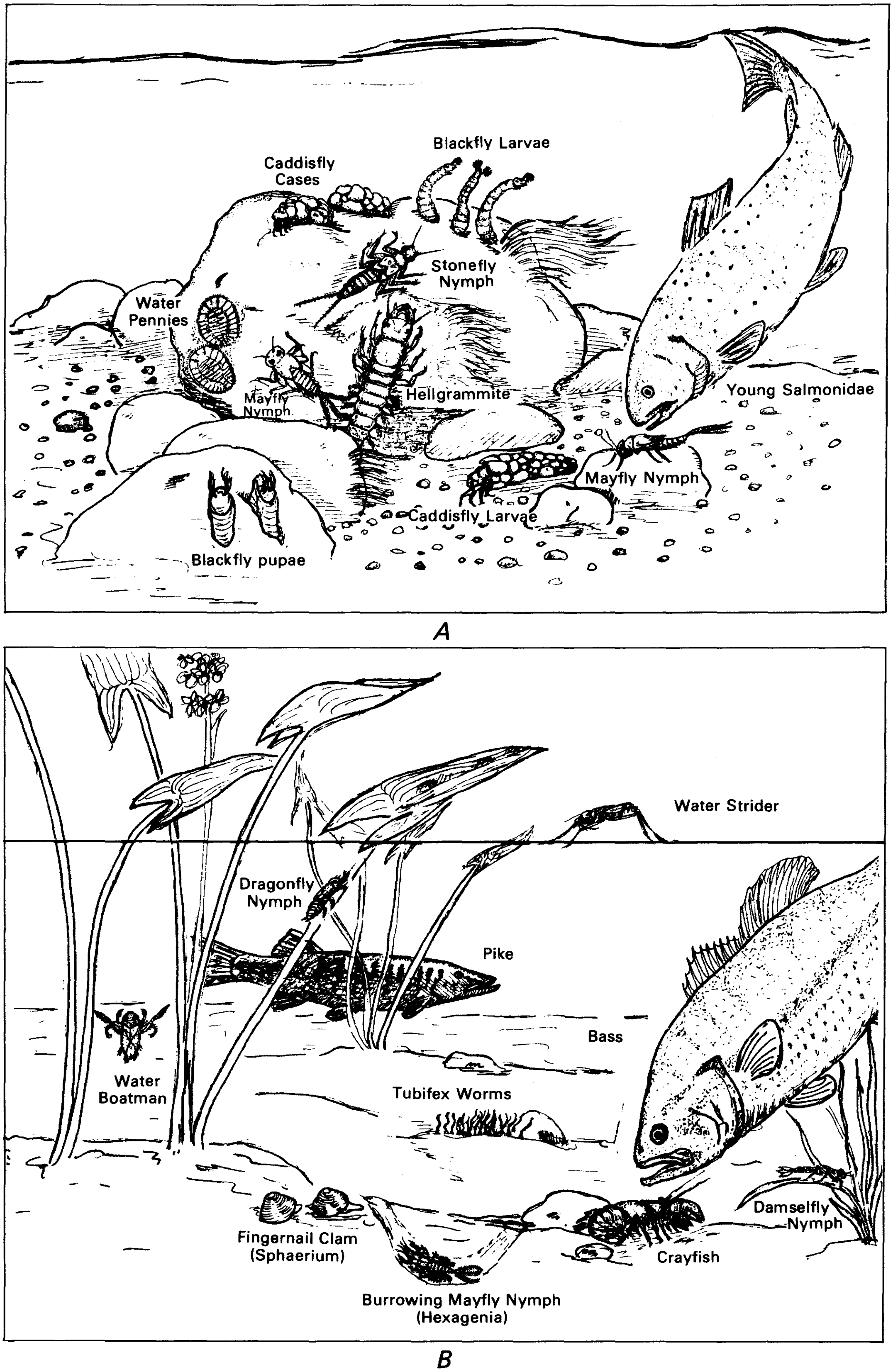

FIGURE 2. Typical inhabitants of a rapid stream, *A*, and a slow stream, *B* (modified from Smith, 1966, p. 199; and Usinger, 1967, p. 121, respectively).

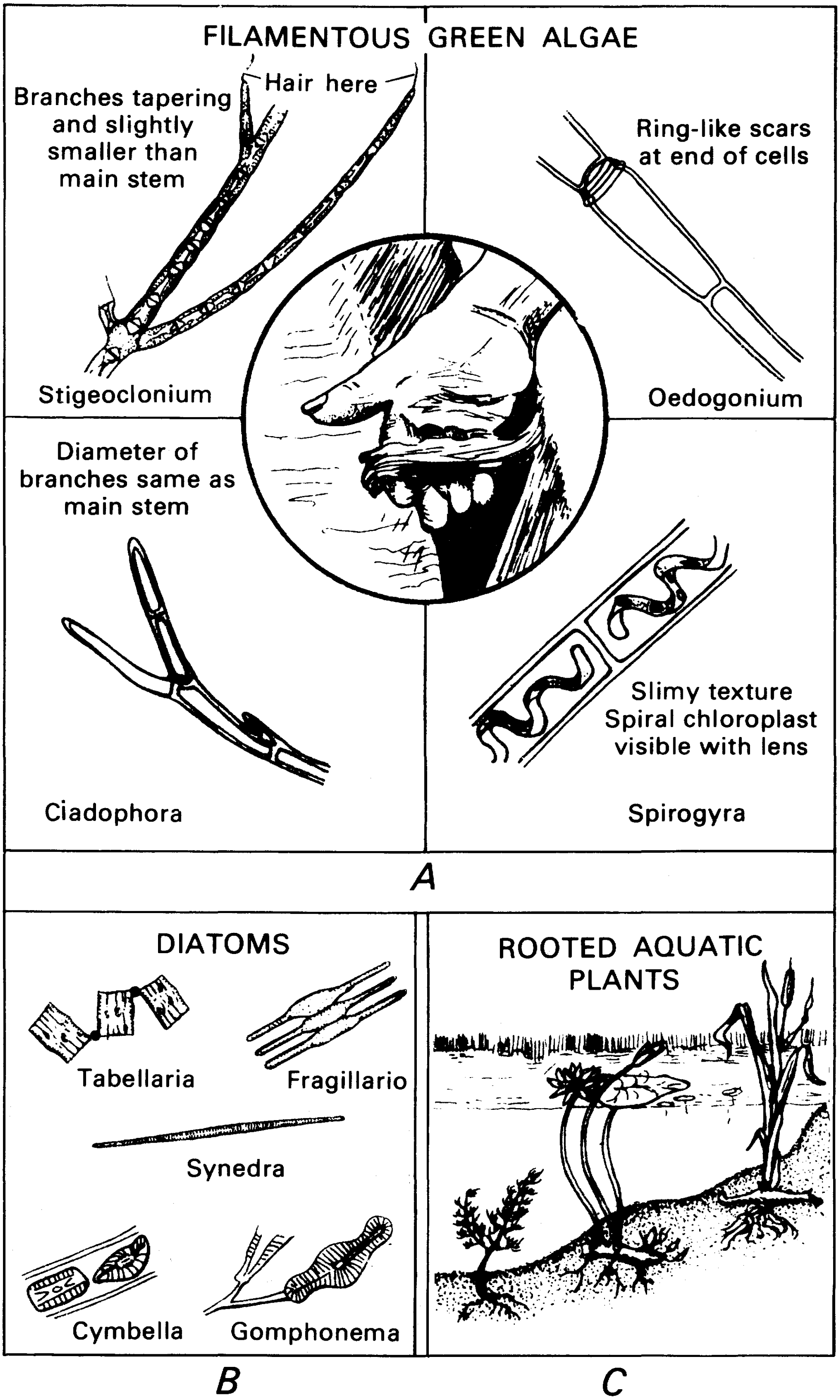

FIGURE 3.—Aquatic plants. *A*. Examples of filamentous green algae as they appear under the microscope. *B*. Typical stream diatoms as they appear under the microscope. *C*. Rooted aquatic plants or macrophytes.

The deep, sediment-laden water of large rivers is unfavorable for the growth of algae. The deposited sediment smothers the plants and the suspended sediment diminishes light which is essential to all green plants. It is noteworthy that algal problems were unknown in the Missouri River until impoundment decreased the suspended-sediment concentration. Thereafter, nuisance populations of algae occurred in the clearer water.

ANIMALS

An account of the animal life or fauna of streams may conveniently begin with the most familiar and advanced group, the vertebrates, which includes all animals with a backbone and an internal skeleton. Although the fishes are the only truly aquatic vertebrates found in our streams, various others, such as frogs, salamanders, turtles, snakes, birds, and mammals are associated closely with the water.

The second and much more numerous group of animals is characterized by the absence of a backbone. Members of this group are collectively called the invertebrates, and they include the dominant forms of animal life in the oceans, on land, and in freshwaters. Familiar examples are worms and clams. The Phylum Mollusca has many marine representatives, but some, snails (fig. 4*A*) and mussels (fig. 4*B*), occur in freshwater.

The Phylum Annelida or segmented worms also are found in marine, terrestrial, and freshwater environments. Freshwater examples are the tubificid worms (fig. 4*C*) and the leeches (fig. 4*D*).

Other smaller phyla contain a variety of animal forms which can be abundant in some samples. Among these are the Bryozoa or "moss animals" (fig. 4*E*), the Platyhelminthes or flatworms (fig. 4*F*), and the Porifera or freshwater sponges (fig. 4*G*).

Many water-living invertebrates belong to the arthropods, a large group or phylum of animals having jointed limbs and an external skeleton which surrounds the muscles and organs of the body. Lobsters and crayfish are examples. The Phylum Arthropoda, as it is known to the zoologists, is subdivided into classes, several of which (Crustacea, Arachnida, and Insecta) include important members of the freshwater fauna.

The Class Crustacea has both small and large examples. Many of the smallest crustaceans are found in the plankton. The larger forms such as the crayfishes (fig. 4*H*), amphipods (fig. 4*I*), and isopods (fig.4*J*) live among plants or on the bottom with other members of the benthos.

The Class Arachnida are arthropods with eight legs. They include water-spiders and water-mites. Although numerically insignificant, the tiny brilliant red mites often are seen in samples of the benthos.

Members of the Class Insecta are characterized by having six legs, and, in the adult, usually one or two pairs of wings. Because this group includes many of the most important freshwater animals, it requires more attention. The insects are divided into categories called orders, for the purpose of classification. The young stages of some orders have the same general build as the adults, from which they differ only in their smaller size and lack of complete wings and reproductive organs; they are called nymphs (fig. 5*A*), and their type of life cycle is called gradual metamorphosis because the change in size and shape from immature to adult is gradual. The Order Plecoptera or stoneflies (fig. 6*A*), the Order Ephemeroptera or mayflies (fig. 6*D*), and the Order Hemiptera or true bugs (figs. 5*A* and 6*E*) all have aquatic nymphs, but the adults breathe air and usually live out of water.

The young stages of other insect orders are distinctly different from adults: they are called larvae (fig. 5*B*). A larva does not give rise directly to an adult as a nymph does, but enters a quiescent stage, the pupa (similar to a cocoon of a moth) in which its tissues are assembled into those of the adult insect. This type of life cycle is called complete metamorphosis. Orders with larvae are the Trichoptera or caddisflies (fig. 6*F*), the Megaloptera or hellgrammites (fig. 6*G*), and the Diptera or two-wing flies of which the Chironomidae or midges (fig. 6*H*) and Simuliidae or blackflies (fig. 6*I*) are but two examples. The Coleoptera or beetles (fig. 5*A* and 6*J*), of which a few are aquatic, live in the water both in the larval and adult stages. A few other insect orders have occasional aquatic species.

BACTERIA

The bacteria play an important, although little understood, role in the ecology of streams. Most kinds are too small to see, except with the aid of a high-powered microscope, but some cluster in such vast numbers that the mass becomes visible. The white or brown, woollike sewage fungus or *Sphaerotilus* is actually a type of bacterium, and the red or yellow substance often seen in springs or

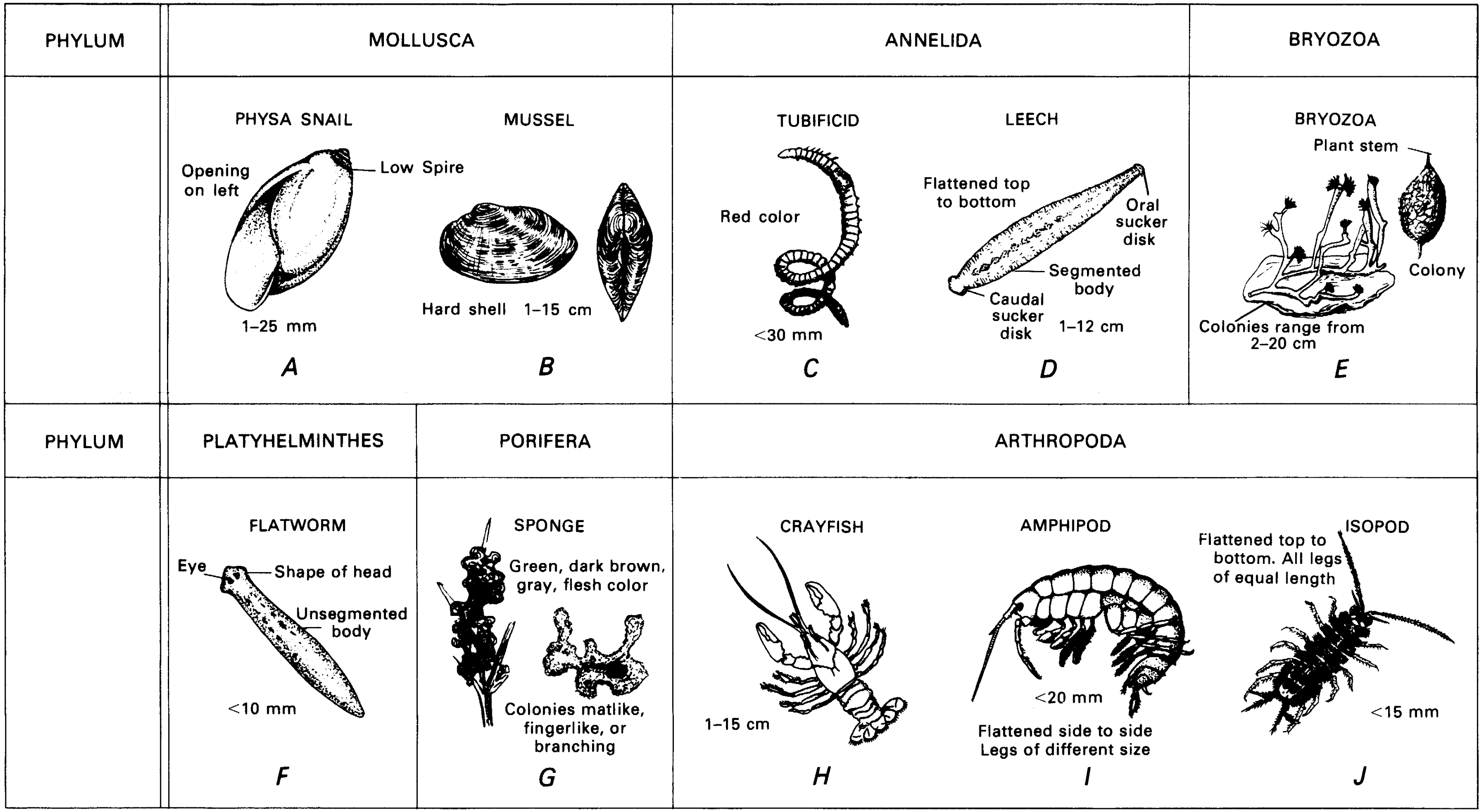

FIGURE 4.—Examples of major phyla of benthic invertebrates.

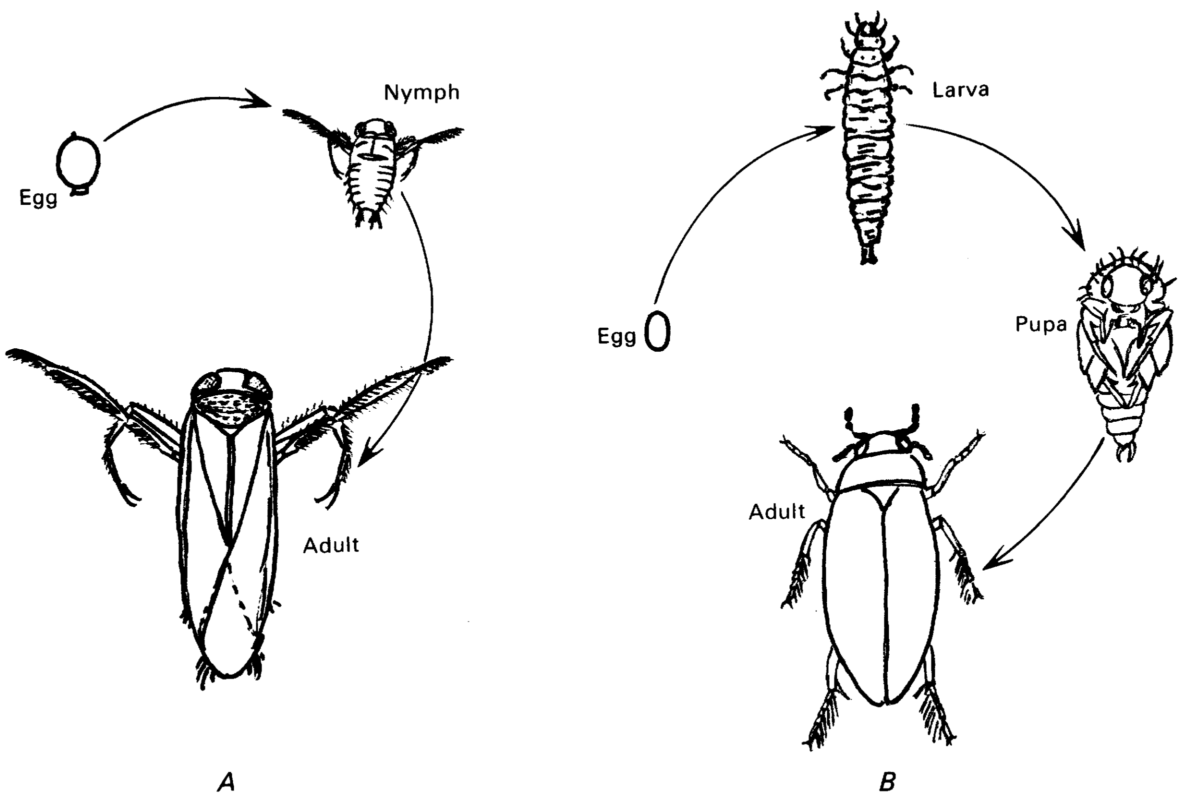

FIGURE 5.—Types of insect life cycles. *A*. Gradual metamorphosis. *B*. Complete metamorphosis.

seeps is a product of innumerable iron bacteria. Most bacteria, like the fungi, are important in the decomposition of organic material and in the recycling of substances in the aquatic ecosystem.

The foregoing paragraph relates to the natural bacterial populations of water, but these are not as familiar to the water resources investigator as are the so-called indicator bacteria. Certain bacteria inhabit the intestine of animals and are present in appreciable numbers in a sample of water, the source of the sample is considered to have a disease-producing potential. Although widely used, total coliform bacteria count is least informative of the sanitary quality of water, because members of the coliform group also occur naturally in soil, water, and plants as well as in feces. Fecal coliform bacteria are a part of the coliform group that is present in the gut or feces of warmblooded animals, and their presence may indicate recent and possibly dangerous contamination. The fecal streptococci bacteria are being used increasingly as indicators of significant contamination of water because the normal habitat of these organisms is the intestine of man and animals. Fecal streptococcal data verify pollution and may provide additional information concerning the time and origin of pollution.

BIOLOGICAL EFFECTS OF POLLUTION

It is well known that unaltered "natural" streams have a definite type of animal life (fauna), and that, in general, the same major groups of organisms occur even on different continents. It also is a well established fact that going downstream from source to mouth one passes through a sequence of more or less well-defined zones, each with its characteristic, but generally similar, fauna. It seems clear, therefore, that slight changes in temperature, dissoved solids, sediment, oxygen regime, and other natural factors induce slight changes in composition of the aquatic life. Different organisms are affected at different levels of these natural changes and the initial biological effect is in the relative abundance of the organisms in the community. For example, stoneflies decline and mayflies increase in relative abundance as one goes downstream.

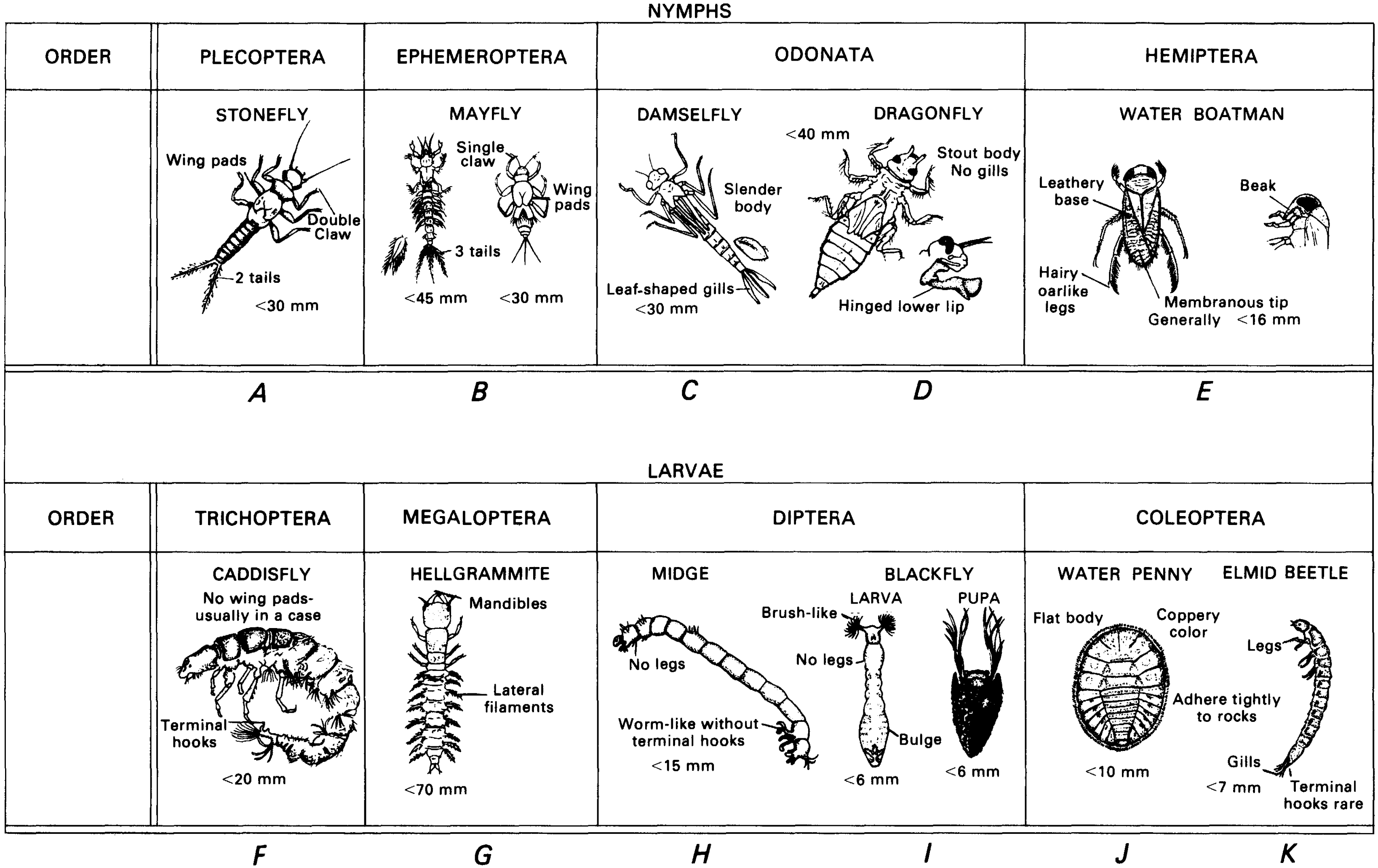

FIGURE 6.–Typical immature aquatic insects. *A*. Plecoptera or stonefly. *B*. Ephemeroptera or mayfly. *C–D*. Odonata or damselfly and dragonfly, respectively. *E*. Hemiptera or true bug (shown is water boatman). *F*. Trichoptera or caddisfly. *G*. Megaloptera or hellgrammite. *H–I*. Diptera or two-winged fly (shown are Chironomidae or midge and Simuliidae or blackfly, respectively). *J–K*. Coleoptera or beetle (shown are water penny and elmid bettle, respectively).

It was mentioned that in an unpolluted stream, a balance exists between the plants and animals that interact with the environment to make up the ecosystem. When a river becomes polluted with organic matter such as the sewage from a small town, a new source of energy is introduced and the whole balance of the ecosystem changes. This extra energy results in a shift and sometimes an increase in the animal population. Very often, the increase is not in the plant-eating animals, but in the animals that feed on detritus. Also, not all animals show the same resistance to the effects of pollution, and the ones that are least tolerant of the new conditions soon begin to disappear. The animals that can survive have an abundance of food, fewer competitors for food and living space, and possibly fewer enemies. The result is that the surviving detritus-feeding species may form very large populations under these peculiarly favorable (to them) conditions.

Three distinct types of pollution may be distinguished: (1) materials already present in the natural ecosystems, (2) poisons and chemicals that normally are not present in nature, and (3) sediment. In the first, such as the example of sewage introduction, there are native organisms that can use and degrade the material, often with an increase in primary productivity. In the second, there may be no organisms capable of using or degrading them, and the substances may slowly accumulate in the environment. Toxic wastes greatly change the biotic community and, in severe cases, eliminate all aquatic life in the affected stream reach.

The third category of pollution results from abnormal amounts of sediment entering a stream. Among the detrimental effects of sediment are impaired light penetration which decreases the amount of plant growth; filling the spaces between rocks, thus depriving many animals of their hiding places; and coating the streambed, which eliminates clinging animals. Thus, the typical fauna disappears and is replaced by burrowing or tube-building species (Hynes, 1960). If sedimentation is very heavy, even these animals will be smothered and destroyed. Silting of streambed gravels affects salmon and trout reproduction by coating the eggs, by decreasing the oxygen supply, and by interfering with the interchange of stream and intragravel water. Suspended particles also may injure gills and other organs of aquatic animals.

In summary, the foregoing examples illustrate the ways in which biology relates to water quality. The basis for the biological evaluation of water quality is that samples of the organisms, such as the benthic invertebrate animals, from an unpolluted reach will show clear differences in abundance and kinds, compared to samples from a polluted reach. Moreover, different types of pollution produce different biological effects, and so the type of change in the aquatic biota can be informative of the character of the pollution event. Biological analysis also makes possible the detection of a transient or intermittent discharge of pollution which may not be detected in a periodic chemical sampling program.

BIOLOGICAL MONITORING OF WATER QUALITY

The fact that streams are a mosaic of microhabitats characterized by differences in bed material, light, current, and other factors, to which the organisms respond makes biological sampling extremely difficult. This subject is discussed more fully in Greeson and others (1977). A practical approach to biological monitoring is to concentrate on only a part of the habitat in order to standardize and simplify the sampling problem. Although this gives only a partial biological picture, it is a useful means of detecting changes that might occur. After all, there is no point in measuring everything biological; just as there is no point in performing every possible chemical analysis.

SAMPLING

We can distinguish two general types of biological samples at a stream site: (1) samples for transient properties such as bacteria or plankton, and (2) samples for integrative properties such as periphyton or benthic invertebrates. The bacteria and plankton are collected in a grab sample of water which, even though depth integrated, represents only an instantaneous condition, a limitation shared with most chemical samples. These grab samples represent the condition or quality of the parcel of water from which the sample was taken at the time of collection. However, the parcels pass continuously downstream and are replaced by others, which may have had different histories and, hence, have different compositions. Therefore, the bacteria or plankton densities in samples taken at a fixed site vary both qualitatively and quantitatively with time, depending on many environmental and biological factors. They are, nevertheless, indicative of the instantaneous condition of the water.

The periphyton and benthic invertebrates are resident communities of individuals that move very little, if at all, and, consequently, are captives of their particular reach of stream throughout their lifetime in the water. The composition of these communities, then, is indicative of the prevailing environmental quality. A change in the conditions will result in a change in the organisms; and, for this reason, the integrative type of sampling is especially valuable for detecting water-quality trends with time.

The two sampling approaches are illustrated by the following analogy. If one wanted to evaluate the economy of a small town, he would be advised to consider the income of the resident population, rather than that of the passengers on a train passing through the town. The residents more clearly reflect the prevailing conditions (environment) than do the transients.

ARTIFICIAL SUBSTRATES

We have mentioned the difficulty of sampling biological populations in the highly variable stream environment, and have concluded that samples of selected biotic communities would suffice for biological monitoring. A useful approach is to place artificial devices (substrates) into the stream in a standardized way, leave them long enough to become colonized by the resident periphyton and benthic invertebrates, and then remove the devices with their populations for analysis. The periphyton is indicative of the nutrient condition of the water; the benthic invertebrates reveal the probable extent to which the stream has been altered from the "natural" condition. When samples are collected in the same way at various times at a given sampling site, long-term changes or trends in water quality are shown by changes in the biota.

These and other methods for determining the biological and microbiological properties of streams are given in Greeson and others (1977).

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Phytoplankton

By George A. McCoy

ABSTRACT

The most common freshwater phytoplankton consist of diatoms, green algae, and blue-green algae. Other groups frequently found include dinoflagellates and euglenoids. The abundance and composition of phytoplankton communities are influenced by the physical and chemical environments and by seasons. Most bodies of water contain a phytoplankton community that typifies the environmental factors. In many streams and lakes, phytoplankton are the principal primary producers.

INTRODUCTION

Plankton is the community of suspended or floating organisms which drift passively with water currents (Greeson and others, 1977). The plant component of the plankton is called the phytoplankton. In its broadest sense, the term phytoplankton includes algae, fungi, and bacteria. However, only the algae are considered in the following discussion.

Phytoplankton, though usually inconspicuous, are extremely important in standing bodies of water (lakes, ponds, and the ocean). These organisms are the primary producers of organic matter and oxygen on which all animal life depends. The total photosynthetic production of organic carbon by phytoplankton is approximately equal to that of terrestrial vegetation. Because of the central importance of these organisms in aquatic ecosystems, it is lamentable that our understanding of the factors and processes that control distribution, periodicity, and seasonal variability of phytoplankton is vague and sometimes fragmentary. It is possible, however, to list the nonbiotic and biotic factors that influence phytoplankton communities.

KINDS OF PHYTOPLANKTON

The most common freshwater phytoplankton are diatoms, green algae, and blue-green algae. Diatoms are distinguished by variously ornamented cell walls or frustules of silica. The ornamentation includes long thin lines which may be either slits or ridges in the frustule, pores which form a distinctive pattern, and in some species, spines. The pigment in diatoms is contained in structures called chloroplasts and is yellow-green or gold in color. Green algae have cell walls of cellulose, and the chloroplasts are grass-green. These organisms may occur as single cells, colonies or filaments (fig. 7). Blue-green algae differ from green algae and diatoms in that their cells have no chloroplasts or nuclei. They have photosynthetic pigments, but in many ways the structure of the cell is more like that of the bacterium than the structure of a plant cell. Other groups of phytoplankton that are important in some freshwater lakes are dinoflagellates (fire algae) and euglenoids (resembling pigmented protozoans).

ENVIRONMENTAL FACTORS

The physical nature of the aquatic environment affects both the abundance and species composition of the phytoplankton community. Warm waters typically have a greater abundance of phytoplankton than do cold waters. Given a warm body of water and a cold one with the same concentration of inorganic nutrients, the warm water probably would support a larger standing crop of phytoplankton, simply because the metabolic rate of the organisms increases with temperature. In cold-water lakes, or under the ice in temperate warm-water lakes, diatoms often are the primary component of the phytoplankton. As the water warms, diatoms generally become less abundant and the green algae increase; if nutrients are abundant and as the water warms further, the blue-green algae become dominant.

The depth of light penetration in water is the critical ecological factor that determines the depth

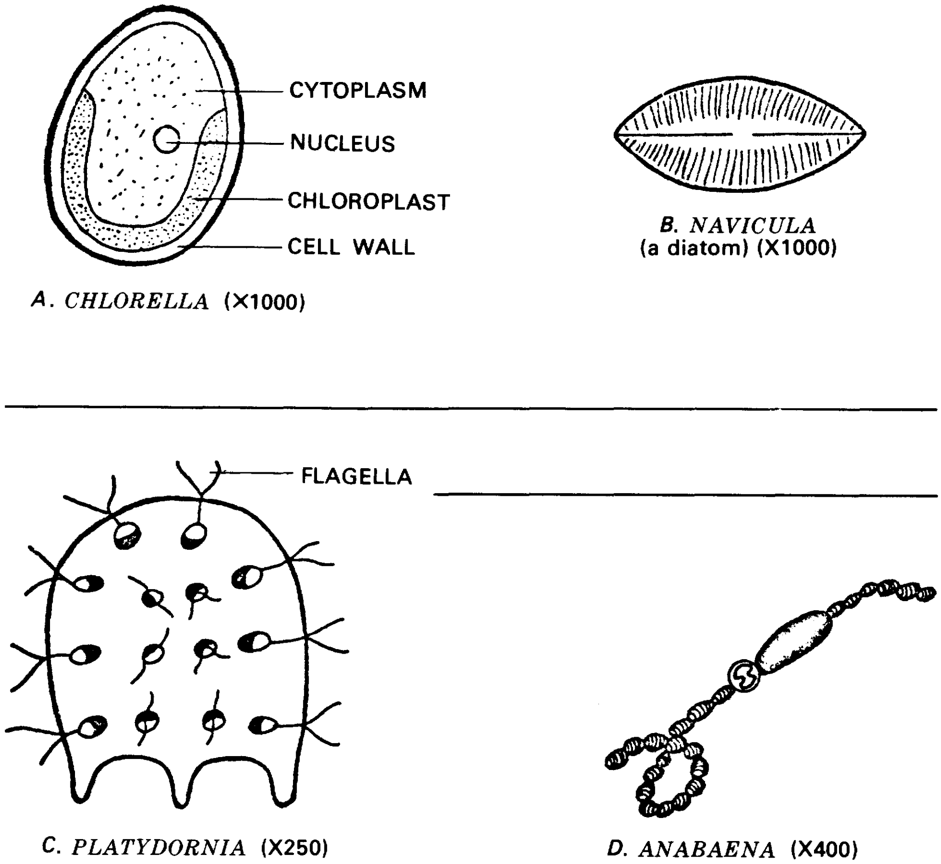

FIGURE 7.–Examples of unicellular (*A*, *B*), colonial (*C*), and filamentous (*D*) planktonic algae.

at which phytoplankton can live in the water column. Light penetration is reduced by the surface disturbance, the amount of suspended particulate matter, and water color. The quantity of phytoplankton itself may affect the depth of light penetration and restrict phytoplankton to a narrow zone near the surface. The euphotic zone is the lighted zone in which the rate of photosynthesis is greater than the rate of respiration. The compensation depth is the depth at which the rate of photosynthesis is equal to the rate of respiration. Below this depth is the aphotic zone where respiration is greater than photosynthesis (fig. 8).

A third physical factor which may affect phytoplankton abundance and distribution within a body of water is wind. In shallow lakes, wind may cause a mixing action which stirs up the bottom sediment and adds nutrients to the water column, contributing to the productivity of the lake or pond. Wind also may affect the horizontal distribution of the phytoplankton of a lake, concentrating them on the windward side. This is an important consideration in phytoplankton sampling.

Phytoplankton affect and are affected by the chemical composition of the water. Most phytoplankton have a narrow range of tolerance for salt concentration. Certain metals, including copper, lead, and aluminum, are toxic to algae. Algae are more sensitive to copper than are aquatic animals; therefore, copper has been used widely as an algacide. Some phytoplankton species are characteristic of lakes with hard water (high carbonate and bicarbonate content and alkaline pH) while others are found more often in soft water (low dissolved-solids content and acid pH). Acid bogs, for example, have a unique algal flora, usually dominated by a group of green algae, the desmids.

Phytoplankton are essentially autotrophic; that is, they produce their own food from inorganic substances. They require a large number of inorganic nutrients, including inorganic carbon

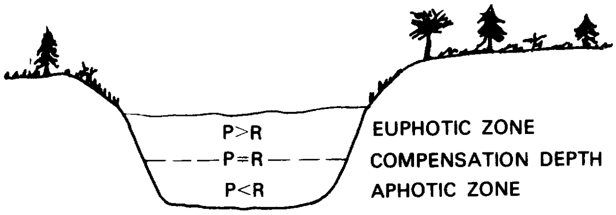

FIGURE 8.–Diagram of a lake showing euphotic zone, compensation depth, and aphotic zone. *P* is rate of photosynthesis, *R* is rate of respiration.

(usually derived from CO_2 or HCO_3), nitrogen, phosphorus, potassium, sulfur, calcium, magnesium, silica, nitrogen, iron, and a number of elements in trace quantities, including zinc, copper, boron, molybdenum, and cobalt. In recent years, a large body of evidence has shown that many algae, if not most, are partly heterotrophic: (1) they require one or more organic compounds for nutrition, or (2) growth is enhanced by the presence of organic compounds or growth factors such as sugar or a vitamin.

With the recent concern over cultural eutrophication of lakes, the nutrients which limit growth of phytoplankton have been receiving an increasing amount of attention. Nutrient limitation is based on the concept that when one of the essential materials needed for growth approaches the critical minimum, that material will limit the amount of growth. Some investigators have argued that CO_2 is often the nutrient that limits phytoplankton growth; now, however, the consensus is that CO_2 limitation of primary production is restricted to a few rare instances, usually in soft-water lakes. In a few lakes a trace element, vitamin, or other organic growth factor has been identified as limiting; however, most limnologists agree that phosphorous is most commonly the limiting nutrient. It was on this basis that Canada banned detergents containing phosphates within the drainage area of the Great Lakes. Nitrogen is sometimes a limiting nutrient, but is secondary in importance to phosphorous. Nutrient-limitation is a complex phenomenon and may vary with the geology, geography, and sources of nutrient input into the lake. The limiting nutrient in a specific body of water also may change with the season.

To even the casual observer, it must be obvious that plants alter the nature of the environment. Phytoplankton are no exception. Respiration and photosynthesis can alter appreciably the concentrations of CO_2 and oxygen in the water. A change in the CO_2 concentration will, of course, affect the pH. In lakes with hard water, the utilization of CO_2 by plants causes a shift in the chemical equlibrium which results in the formation of calcium carbonate from bicarbonate and dissolved calcium. The precipitation of calcium carbonate on the lake bottom and on the surface of algal cells takes the form of a hard encrusting layer called marl. This is such a prominent feature of some lakes that they are termed marl lakes.

Phytoplankton communities also are affected by other organisms in the water column. Grazing by zooplankton and to a lesser extent by fish may affect both the abundance and species composition of phytoplankton. There have been many studies which show an inverse relationship between zooplankton density and phytoplankton standing crop.

Virtually all standing bodies of water have a resident phytoplankton community. Slow-moving rivers also maintain a phytoplankton community, and phytoplankton may be important in sidearms or among thick growths of rooted aquatic plants in moderately fast-flowing streams. It has been determined that phytoplankton numbers increase progressively downstream. Water samples from headwater streams primarily contain benthic algae that have been dislodged from the bottom. In slower moving waters near the mouth, true phytoplankton organisms can be found.

Phytoplankton data from streams are difficult to interpret. It is often possible, from the taxonomic identification, to determine if an alga in the water column is a true planktonic organism or a benthic alga that has been dislodged. It is, however, much more difficult to determine if the organism has developed as part of the stream flora or has been washed in from lakes or swamps in the drainage. Several investigators have proposed that algae suspended in the water column in rivers and streams be termed drift algae. This terminology has some merit, because it is much more descriptive of the organisms that are collected in a water sample from a stream than is the term phytoplankton.

The phytoplankton population fluctuates rapidly during the course of a year. Phytoplankton may multiply very rapidly to a peak, or bloom, and then decline. Bloom conditions often are associated with warm summer weather, but they also may occur in the winter under ice cover. In a given body of water, not only can the phytoplankton density, usually measured in cells per milliliter, change from one day to the next, but the species composition of the phytoplankton may change with time. Figure 9 illustrates the kinds of changes that can be expected in the population of different types of phytoplankton in a temperate lake during the year. In the hypothetical lake, the diatoms are present in significant numbers all year, but are most abundant in the winter. Green algae peak in early summer, and the blue-green algae are dominant in late summer. The figure is intended only as an example to illustrate seasonal changes. The pattern of phytoplankton changes and species composition may vary greatly from one lake to another, depending on the amount of available nutrients, geology of the area, and the climate. In the oligotrophic (having few nutrients) soft-water lakes, for example, the diatoms may be the dominant organisms for the entire year.

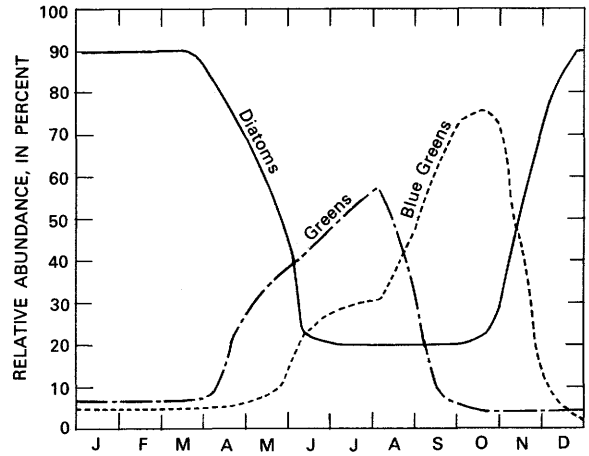

FIGURE 9.–A hypothetical example of the fluctuation in relative abundance of the three major groups of phytoplankton during a year in a temperate lake.

An example of the typical fluctuations of a phytoplankton community during the course of a year is illustrated in figure 10. The pattern of fluctuation in phytoplankton abundance may vary greatly from one lake to another. Figure 10 shows a winter bloom in February and March and two summer blooms, one in June followed by a summer minimum and then a second bloom in August. In other lakes, one or all of these blooms might not occur.

It should be emphasized that phytoplankton may not be distributed evenly, horizontally or vertically, in a body of water. They will be most abundant at a depth where the light penetration is optimum for growth. Horizontal circulation patterns caused by current, wind, lake shape, location of inlets and outlets, and sources of effluents may cause an uneven horizontal distribution of phytoplankton.

IMPORTANCE

The importance of phytoplankton as primary producers in freshwater and marine environments cannot be overemphasized. Phytoplankton are utilized as a food source by zooplankton and fish. Primary production is, of course, necessary for all levels of secondary production, from the smallest invertebrate to fish and aquatic mammals, and results in the production of organic compounds that ultimately are cycled to the fungi and bacteria which act as decomposers.

Photosynthesis by aquatic plants, including phytoplankton, is an important source of the oxygen upon which aquatic forms of animal life depend. However, plants also respire, a process which utilizes oxygen. Given the right conditions–warm water (high rate of respiration), low light levels, and little or no wind (low rate of oxygen transfer from atmosphere to water)–phytoplankton may cause oxygen depletions in a body of water, resulting in fishkills or in severe mortality of certain aquatic insects. Lake Erie at one time produced large quantities of mayflies. The aquatic nymphs of these insects were an important source of food for the walleye. In the late 1950's, the large emergences of adult mayflies ceased. Simultaneously, the walleye fishery experienced a catastrophic decline. Several investigators have suggested that these changes resulted from periodic, short-term dissolved-oxygen depletions caused by a combination of dense phytoplankton populations and warm, calm nights.

Phytoplankton can cause a myriad of other problems in water. Decomposing phytoplankton may accumulate on beaches and cause an unpleasant odor. The "fishy" smell associated with very productive water is actually the odor of decomposing algae. Dense phytoplankton blooms may turn the water a soupy green color, or dead phytoplankton may accumulate on the surface of a lake and create a scum, thus lowering the esthetic value of the lake. Phytoplankton are sometimes toxic to animals. In the marine environment, the so-called "red-tide" is actually a bloom of *Gymnodinium*, a

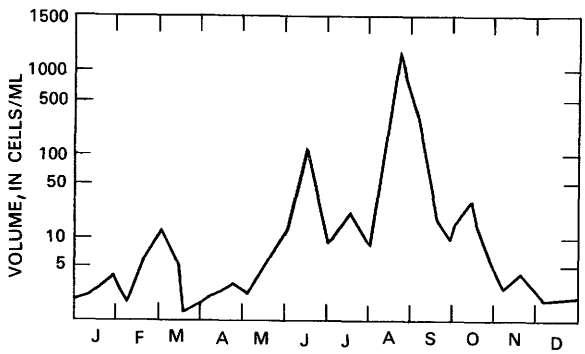

FIGURE 10.–A hypothetical example of changes in the volume of phytoplankton in cells per milliliter in a lake during a year.

dinoflagellate. This organism secretes a toxin which accumulates in the flesh of some fish, and in the digestive glands of shellfish, causing them to be toxic to humans. In freshwater environments, there have been numerous documented instances of livestock poisoning by blue-green algae. In this country, most of the incidents have occurred in the Midwest. Toxicity of algae has been reviewed by Gorham (1964) and Schwimmer and Schwimmer (1964, 1968).

Phytoplankton often are used as indicators of environmental conditions. Numerous lists of indicator organisms have been compiled. However, the concept of indicator organism is gradually being replaced by the more useful concepts of community structure, such as diversity, evenness, similarity coefficients, multivariate analysis, or biomass. Biomass is an especially useful parameter for phytoplankton populations, if it is possible to measure the peak of the bloom. Upon inspection of figure 8, however, it should become apparent that many closely spaced measurements would be necessary to measure the maximum biomass.

A measurement such as the relative proportion of the major groups of algae (that is, blue-greens, diatoms, greens) can give some indication of the productivity of a system. However the amount of information to be gained from a phytoplankton sample is maximized by identification to the species level. There are species of the diatom *Navicula*, for example, that occur both as periphyton and phytoplankton and can be found in eutrophic, mesotrophic, and oligotrophic freshwater, as well as in estuaries and saltwater. To say that *Navicula* is the dominant genus in a phytoplankton sample gives us little information about the sample. *Navicula semen*, however, is found in cool water of low mineral content. *Navicula secreta* is found in freshwater of high mineral content and *Navicula maculata* occurs only in brackish water. *Melosira distans* (a diatom) is abundant in clean unpolluted areas, and *Melosira granulata* is abundant only in eutrophic bays and inshore areas. Many species of *Gomphonema* are periphytic diatoms (living attached) while other species are strictly planktonic in occurrence.

If the objectives of a study are to detect gross changes in water quality, then a low level of taxonomic identification may suffice. Often gross changes can be detected by visual observation. The water may be colored by a dense phytoplankton bloom or there may be a floating "scum" of blue-green or green algae. Species identification is, however, necessary to detect subtle changes. The decision as to whether or not to include phytoplankton data in an investigation and the type of data to be included ultimately are dependent on the objectives of the investigation.

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Periphyton

By George A. McCoy

ABSTRACT

Periphyton, consisting of algae, fungi, and bacteria, will grow on almost any submerged object. They are influenced, however, by physical factors, such as velocity of water movement, temperature, light intensity, and type of substrate. Chemical factors also influence their growth and distribution. Because periphyton are stationary in a given location, they are excellent indicators of environmental conditions.

INTRODUCTION

We have all experienced the trauma of wading a stream with a slimy coating of "moss" on the stream bottom. The "moss" is really periphyton, the assemblage of algae, fungi, and bacteria which are attached to or live on submerged objects in streams and lakes.

Periphyton will grow on almost any submerged object. It can occur as a thin film on silt or mud surfaces, on submerged branches, roots, logs, or dock pilings, and on rooted aquatic plants. It also occurs as floating or loosely attached layers in lakes or in the shallow areas of sloughs or slow-moving areas of streams.

Although periphyton organisms are usually microscopic, they often form masses or clumps that are visible to the unaided eye. Some genera form long entangled masses of threadlike filaments which are very conspicuous. These masses often contain several kinds of filamentous algae growing together; *Cladophora*, *Ulothrix*, *Oedogonium*, and *Spirogyra* are common members of such an association. They usually are attached to the rocks by rhizoids or rootlike structures.

These assemblages also commonly contain several species of diatoms, another kind of algae. Many of the diatoms are attached to the substrate by a jellylike substance. Other diatoms occur on stalks or in gelatinous tubes. Still other diatoms, particularly those on mud and sediment, are motile.

Clumps of periphyton also may form cushions on the surface of submersed objects. This is particularly true of the blue-green algae. Periphyton are undoubtedly the most important primary producers in the flowing water environment. Primary producers are those organisms that manufacture sugar from inorganic carbon through the process of photosynthesis. The periphyton are generally of secondary importance to phytoplankton in lakes, but several studies indicate that in some lakes they are equal to or even more important than phytoplankton as primary producers.

PHYSICAL FACTORS

The physical factor which has the most influence on periphyton is the flow or motion of the water. Several studies have shown that some species of periphyton colonize only those areas in stream where the water is constantly moving. For certain species, the water must be moving at a velocity greater than some threshold value before the forms can grow.

Moving water constantly replenishes the supply of nutrients to attached nonmotile organisms. It has been shown that up to a certain point, phosphorus uptake by algal cells and the amount of primary production increase as current velocity increases. Observation will reveal that periphyton commonly are most abundant at low flow when the water is clear, and are less abundant during and immediately after storm events or periods of high runoff, because they are scoured from the substrate.

Temperature has essentially two effects on the periphyton community. All other factors being equal, the amount of primary productivity increases directly with temperature. Warm streams and lakes commonly have a larger standing crop of periphyton than do cold streams. Temperature also affects the species composition of the periphyton.

Some organisms are adapted specifically to cold water. There are numerous examples of algae that occur only in cold mountain streams or in the Arctic. Many green algae are found only in the summer, and most of these organisms seem to be able to tolerate water temperatures as high as 25°C. Still other organisms, including some blue-green algae, are adapted to hot springs and are absent from other environments.

The effects of light intensity cannot always be separated from temperature. However, there are several species of periphyton that are found only in the densely shaded areas of streams, but occur over a wide range of temperatures. The few red algae that occur in freshwater appear to be adapted to low light intensities. Green algae, on the other hand, require a more intense light level and are very sparse in shaded streams. Diatoms as a group seem to occur over a wide range of light intensities, but some studies have indicated that the composition of the diatom community is different in shaded and unshaded areas. It has been demonstrated that light and temperature do not function independently. Algae in colder water seem to grow more efficiently with a higher light intensity than do periphytic algae in warm water.

The nature of the substrate, its texture, stability, and porosity, undoubtedly affects the composition of the periphyton community. The stability of the substrate is perhaps most important. A very different community will develop on fine shifting sand and silt than on a coarse gravel or cobble. Larger or slower growing species require a durable, lasting substrate; consequently, these organisms often are not found on aquatic vascular plants.

CHEMICAL FACTORS

Alkalinity and related parameters, such as hardness and pH of water, have an important chemical influence on the periphyton community. Many organisms are equally abundant in soft and hard water, but others are restricted to acid or alkaline environments. In addition to differences in community composition, the density of organisms in soft or acid water is commonly much lower than in alkaline or hard water.

Many species of periphyton are characteristic of saltwater, while other species have a range of tolerance for salinity. In an estuarine environment, there is a gradual but marked change in the community composition from the marine environment of the ocean through the tidal environment of the gradual freshening estuary to freshwater.

Phosphorus and nitrogen are usually the most important inorganic nutrients. The addition of phosphorus, and in some instances nitrogen, has been shown to enhance periphyton growth in laboratory streams. The increased growth of periphyton downstream from a sewage outfall is probably a direct result of phosphorus additions. In a uniform reach of a stream where there is no additional source of nitrogen or phosphorus, the concentration of these two substances will decrease gradually downstream. This is presumably caused by the uptake of phosphorus and nitrogen by periphyton. Numerous studies have shown that the species composition of periphyton may be very different above and below a sewage outfall; often diatoms are replaced by a luxurient growth of green and blue-green algae. Growth of blue-green algae is enhanced by additions of organic forms of nitrogen and phosphorus. Another inorganic nutrient that is necessary for the growth of some periphyton is silica. It has been suggested that floodwaters carry increased amounts of silica which may stimulate the large increases in diatom populations that occur after a flood.

BIOLOGIC FACTORS

Periphyton organisms are opportunists. That is to say, the organism which can attach and grow most rapidly on a new substrate will probably be most successful in colonizing that particular habitat. Competition among periphyton organisms is not generally for nutrients, but rather for available substrate space. Many invertebrates and certain fish feed on periphyton. These grazing animals play an important role in determining periphyton abundance and distribution, and their feeding patterns can cause irregular distribution of periphyton. The blue-green algae usually are avoided and may even be toxic to invertebrates and fish, but large quantities of diatoms and green algae may be consumed by grazers, often very rapidly. It is sometimes possible to see clear areas on stones around snails and limpets, and several caddisfly larvae are known to graze on periphytic diatoms.

METHODS OF COLLECTION

There are a number of methods of collecting periphyton samples from natural substrates. These methods are illustrated and explained in Greeson and others (1977). Quantitative sampling of natural substrates for periphyton is difficult. If collections of periphyton from natural substrates are to be representative of the community in a reach of a stream, then a sampling scheme must be devised so that collections from all natural substrates found in that reach are obtained.

Sampling programs using artificial substrates have the advantage of standardizing the physical environment. Although the communities that develop on artificial substrates are not necessarily representative of the communities present on natural substrates, artificial substrates do provide information that can be used to compare one site or one stream with another. This assumes, however, that the artificial substrates were exposed in a similar manner and for the same length of time. Artificial substrate samples can be compared for community structure. They also can be used to measure rate of colonization, or the amount of biomass accumulated in a given unit of time in a given area; this information yields a relative measure of the productivity of a stream.

Another useful measurement on periphyton samples is the autotrophic index. Autotrophic refers to organisms in which organic matter is synthesized from inorganic substances (photosynthesis) as compared to heterotrophic organisms, which require organic material as a source of nutrition.

The autotrophic index is the ratio of biomass to chlorophyll *a*. A high value for this index indicates a community with a large number of heterotrophic organisms (bacteria and fungi). A low value indicates a community with predominately autotrophic organisms.

Artificial substrates commonly made of polyethylene strips, plexiglass, or glass microscope slides are suspended in the water for a period of at least 14 days. After retrieval, it is possible to determine chlorophyll or biomass per unit area of the substrate. These determinations yield a relative measure of the productivity of the water. It is also possible to measure the species composition of the community and to compare it directly with the community on a substrate from a different site.

DISTRIBUTION AND OCCURRENCE

The variations of physical and chemical factors in moving waters cause periphyton to be distributed in a very nonuniform manner in a stream. Some organisms will occur near springs, others in slow-moving water or in pools. The community structure also may vary with the nature of the substrate or the degree to which the site is shaded.

The amount of periphyton and the kinds of species in the community also will vary seasonally. Seasonal changes are caused by a variety of physical and chemical influences, including light, temperature, ice-cover, flow, and changes in available nutrients and dissolved solids.

In large slow-moving rivers, however, the seasonal changes are not as great as in small swift streams. It is likely that the environment in a large river varies less in response to climatic fluctuations.

IMPORTANCE

Periphyton often are used as indicators of environmental conditions. A few algal species have a well-defined habitat preference. From the occurrence of one of these species in a body of water, it is possible to infer certain characteristics about this environment. However, the majority of algal species have a broad range of tolerance for habitats or too little is known of their physiology for them to be of value in interpreting the environment, unless they are very abundant. If, however, the entire community is considered, then certain associations of organisms may be discerned from which we can infer that certain conditions exist in that environment. The concept of indicator species, where a particular species is used to indicate a specific kind of pollution, or type of water is, at present, of limited value. However, a large growth of green filamentous algae in a stream usually indicates an abundant supply of nutrients.

The use of whole communities to compare certain aspects of rivers or sites in a particular river is useful, but often cumbersome. The use of mathematical comparisons such as diversity indices, similarity indices, dendrograms, and multivariate analyses are useful methods for determining similarities and differences between communities. These techniques often require some form of computer analysis and will become more useful as we gain a better understanding of the physiology and ecology of the individual organisms.

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Drift Organisms in Streams

By Keith V. Slack

ABSTRACT

Organisms that drift in stream currents generally are invertebrates, primarily mayflies, stoneflies, caddisflies, and blackflies. The amount of drift usually is associated with time, more drift occurring during the dark hours. Some species, however, can be found drifting during the daylight hours. The measurement of drift provides a basis for comparing the water quality in different streams, in that it is affected by several environmental factors.

INTRODUCTION

The earlier paper on "Stream Biology" (in this volume) discussed stream biology and the various means by which stream invertebrates are adapted to maintaining their position in flowing waters. It is to be expected, however, that an occasional organism will lose its hold and be carried downstream by the current. In fact, organisms of all sizes are transported by stream waters. Algae, bacteria, viruses, and the detritus of larger plants and animals are very common in the organic load of streams. The term "organic drift" sometimes is used for this material. However, the term "drift" in stream ecology usually means the downstream transport of benthic invertebrates (measured by the number or biomass of invertebrates per unit volume of water or passing a sampling point in a unit time).

If drift consisted only of the rare, clumsy organism that missed its footing momentarily and became entrained in the flow, it would be of little ecological consequence. Studies have shown, however, that large numbers of benthic invertebrates are found regularly in the drift. During the 24 hours of April 18, 1946, an estimated 64 million invertebrates, weighing 200 kg, passed under Boonville Bridge on the Missouri River (Berner, 1951). A study of a swift trout stream in England concluded that during a year, 19.6 g of organisms drifted over each square meter of bottom which supported a biomass of 1.5 to 3.6 g at any one time (Horton, 1961). These quantities are so large that aquatic biologists have questioned the productive capacity of the streams to withstand such high rates of attrition.

Several types of drift can be distinguished (Waters, 1972). "Catastrophic" drift results from the physical disturbance of the benthic fauna, such as bottom scouring caused by floods, but may result also from drought, high temperature, anchor ice, insecticides or other toxicants, and organic pollution. The effect of catastrophic drift on benthic invertebrate populations can be severe. "Behavioral" drift results from behavior patterns characteristic of certain species. It occurs at night or at other consistent periods of time. Although behavorial drift may occur in large quantities, it does not appear to deplete upstream areas. "Constant" drift is the continuous downstream flow of representatives of all species in low numbers. It has the least effect on the stability of benthic invertebrate populations.

DIEL PERIODICITY

Although several factors have been observed to affect the kinds and amounts of organisms drifting, the rate of drift usually varies between day and night. The discovery, in about 1960, of day-night differences in drift stimulated research on stream invertebrate drift. Studies in many parts of the world have shown that drift usually increases sharply at about the time of full darkness (fig. 11). Increased but variable drift continues throughout the night, then ends with a sharp reduction in numbers at dawn. However, a few species, mostly caddisflies, are day active, showing higher rates of drift during the daytime.

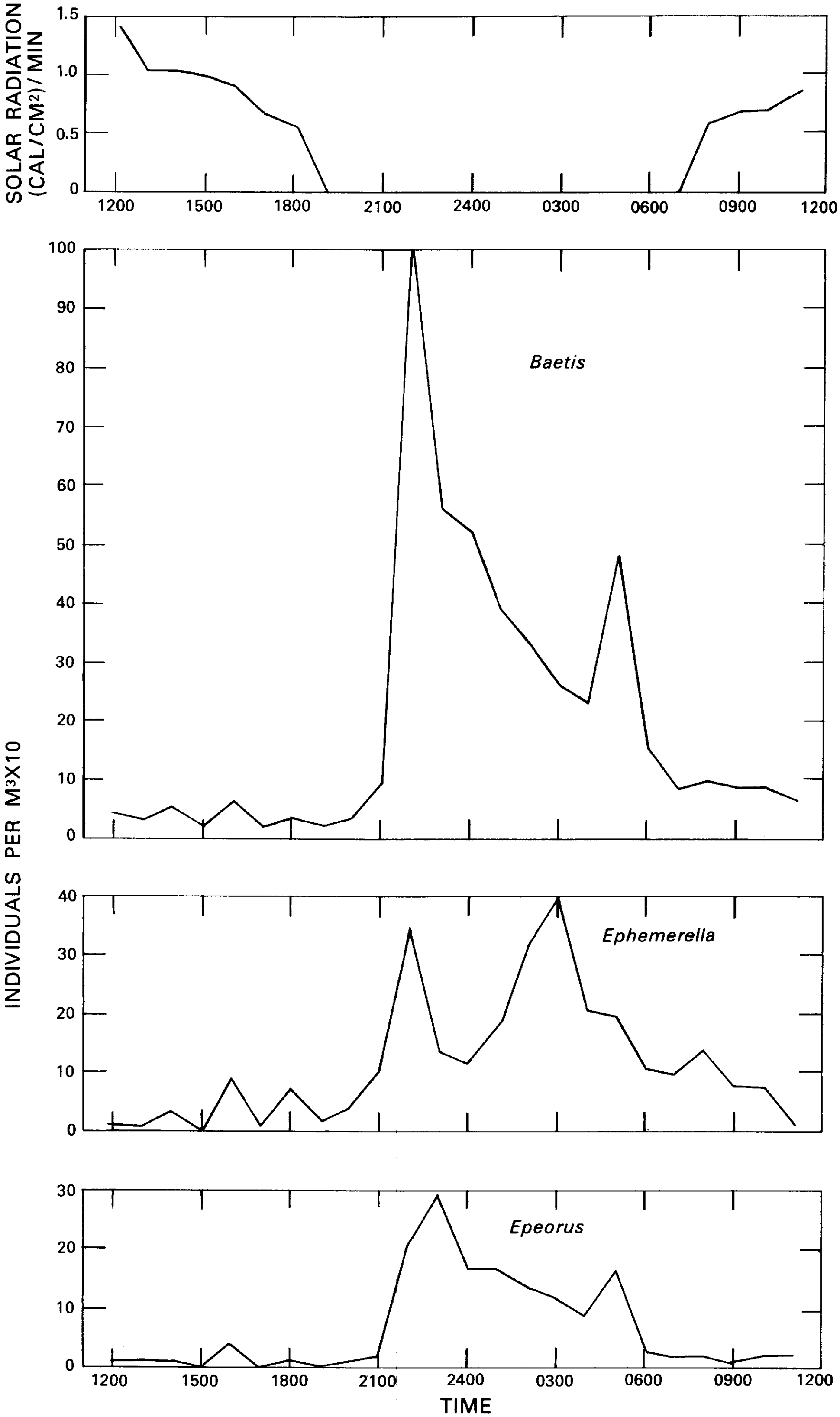

FIGURE 11 – Solar radiation and diel periodicity in the drift of three genera of mayflies, Little Boulder Creek, Idaho, July 12–13, 1977 (Slack, Tilley, and Hahn, unpublished data, 1977).

It is postulated that night-active drift is the result of feeding, and that the nocturnal foraging behavior of stream invertebrates has evolved because darkness provides them the greatest protection agaist predators. Thus, the organisms hide during daylight under rocks or in interstitial spaces, but move to upper surfaces during dark to forage. Herbivores seek algae growing on the tops of rocks, and their predators follow. The result is increased exposure to the current and greater chances of dislodgement of herbivores and predators causing both to exhibit the observed periodicity in drift.

Day-active periodicities may be the result of a direct metabolism-activity relationship to water temperature. As growth occurs, crowding and subsequent loss of living space may result in increased activity, dislodgement, and difficulty of reattachment. This may explain the higher drift which occurs at times of most rapid growth.

Prepupation or preemergence activity in some species may result in a drift periodicity. Light appears to act in an "on-off" fashion, triggering increased activity by many benthic species when it decreases to a threshold intensity of about 1 to 5 lux (0.1 to 0.5 foot-candles) of total energy measured at the water surface. Other environmental factors that affect the amount of drift but not its periodicity include current speed, and, for some species, water temperature. In addition, riffles produce more drift than do pools.

At any one time, the density of drifting organisms is fairly constant in the cross section. Each organism probably moves a relatively short distance downstream during its entrainment before it can reattach or is eaten by a fish or other predator. The total downstream displacement by drift probably occurs in a saltatory fashion in which the drifting organisms frequently are returned to the substrate by turbulence and are replaced by others. Drifting, therefore, is a temporary event in the life of many members of the bottom fauna. However, many organisms fall prey to predators while in the drift, or are carried out of areas which are suitable habitats and ultimately die.

DRIFT ORGANISMS

The most abundant taxa in the drift are amphipods, the insect Orders Ephemeroptera (mayflies), Plecoptera (stoneflies), and Trichoptera (caddisflies), and the Family Simuliidae (blackflies) of the Order Diptera (Waters, 1969). In all of these groups, there are species exhibiting no apparent behavioral drift, even though they are abundant on the stream bottom. Other groups have been reported in the drift in fewer numbers. Almost all amphipods, mayflies, stoneflies, and blackflies are night active, whereas caddisflies have both night- and day-active species. Notably absent in drift periodicities are most burrowing forms, large strong-swimming predators, mollusks, stone-cased caddisflies, and dipterans other than blackflies. Chironomidae (midge) larvae apparently show little or no drift periodicity. The entire mayfly genus, *Baetis,* exhibits definite periodicity. *Baetis,* some species of *Gammarus* (amphipods), and some blackflies are the main groups exhibiting extremely high rates of drift (Waters, 1969). In drift downstream from impoundments, lake benthos and zooplankton may dominate, and may show diel periodicity.

RELATION OF DRIFT TO PRODUCTION AND LIFE CYCLES

Early observations of drift magnitude led to speculation as to its role in population dynamics and the processes by which upstream areas adapted to such apparent high rate of attrition. One of the earliest discussions (Denham, 1938) suggested that overcrowding and competition contributed to drift. A second suggestion (Müller, 1954) has come to be known as Müller's "colonization cycle." It postulated an upstream flight of adults for egg laying with a concentration of eggs and young larvae in the upper reaches. As small larvae grew, they were forced to seek new space, and the consequence was downstream drift, which also resulted in colonization of all suitable habitats throughout the stream. Emergence was followed by an upstream return of the adults to complete the cycle. Thus, drift kept population densities reduced to the carrying capacity of the environment and provided a mechanism for colonization.

No evidence is available to show that behavioral drift reduces population densities below carrying capacity. If it does not, drift merely represents production that exceeds the carrying capacity of the stream. Neither upstream compensation nor the excess production hypothesis is universally applicable. It is certain that variation exists and that a variety of mechanisms are involved in the ecology of stream invertebrate drift (Waters, 1972).

METHODS OF DRIFT SAMPLING

Sampling methods for drift analysis are described in U.S. Geological Survey Techniques of Water Resources Investigations, Book 5, Chapter A4 (Greeson and others, 1977), Elliott (1970), Weber (1973), American Public Health Association and others (1976), and Hellawell (1978). Results are expressed as drift rate, the biomass or number of invertebrates passing a sampling point in unit time, or as drift density, the biomass or number of invertebrates per unit volume of water.

APPLICATION OF DRIFT DATA

Invertebrate drift is a fascinating example of a natural biological cycle which is of interest in water-resources investigations for several reasons. One consequence of drift is that unpopulated or depopulated areas are recolonized rapidly by animals from upstream. The areas affected by drift in this way range from artificial substrate samplers to entire reaches of river channel. Measurement of drift provides a basis for comparing streams (Diamond, 1967) and is a means of sampling benthic invertebrates in reconnaissance studies (Slack and others, 1976). It also is an indicator of water quality (Larimore, 1974). Qualitative or quantitative changes in drift can indicate the effect of insecticides or other toxicants on a stream biota (Coutant, 1964). The study of invertebrate drift is an important method for investigating insect life histories (Anderson, 1967) and secondary production (Waters, 1962, 1966). Some species of fish, notably the brown trout, feed largely on drifting organisms (Hynes, 1970). This is the basis of angling with a wet artificial fly.

Much remains to be learned about invertebrate drift and its relation to the stream environment. We can expect that knowledge developed by research on drift will contribute increasingly to our understanding of the function and succession of stream communities. This will enhance our ability to use ecological approaches in water resource monitoring and appraisal.

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Family Chironomidae (Diptera)

By Larry J. Tilley

ABSTRACT

The chironomids, or midges, have complete life cycles–eggs, larvae, pupae, and adults. The larva are primarily aquatic and can be found in virtually every aquatic habitat. The distribution of the seven subfamilies is predictable; therefore, the presence of a subfamily in a particular aquatic habitat is indicative of the environmental conditions.

INTRODUCTION

One of the most abundant and diverse groups of insects is the Order Diptera or two-winged flies. Familiar examples are house flies, fruit flies, and mosquitos. Not so familiar by name, perhaps, but certainly very commonly seen by anyone working around bodies of water are the small delicate midges (fig. 12*D*). These insects sometimes swarm in untold thousands, especially in the evening around water or moist places. Midges do not bite or suck blood, but by their very numbers, they can be a nuisance to campers or fishermen. Recently, the construction of residential lakes near real estate developments in southern California created ideal habitats for midges. Large swarms of midges became a severe nuisance around residences, marinas, restaurants, and other commercial buildings resulting in stained walls and draperies, contaminated food, and reduced real estate values (Mulla, 1974; Ebeling, 1975). The true midges, or technically speaking, Chironomidae, are familiar to aquatic biologists because of their nearly universal presence in rivers, creeks, lakes, and ponds throughout the world. Although Chironomidae are only one of several families of the Order Diptera, they are abundant in numbers and species and usually comprise about one-third to one-half of most benthic invertebrate samples.

Besides being extremely important members of the aquatic ecosystem, chironomids have the distinction of being one of the more difficult groups of benthic organisms to identify to species. Although there is no reliable estimate of the total number of chironomid species, about 5,000 species have been described and little work has been done in large areas of the world such as Asia and the Tropics (Oliver, 1971). Coffman (1978) estimated that about 2,500 chironomid species inhabit North America. Both Oliver and Coffman reported that chironomids comprise one-fifth to one-half of the Arctic insect fauna, and that some well-studied lakes and streams have 100–200 species of chironomids.

Chironomidae are holometabolus, that is, they have a complete life cycle, egg-larva-pupa-adult, analogous to that of a butterfly or moth (fig. 12). The larvae (fig. 12*B*) are of most interest to aquatic biologists because of their abundance in benthic invertebrate samples. Most midge larvae are aquatic, but few are found in decaying matter, under bark, or in moist ground. Most aquatic larvae live in tubes or cases constructed of sand grains and organic debris cemented together by fluids from salivary glands. Some larvae, known as bloodworms, are red because of the unique presence of hemoglobin in the blood. Chironomid larvae move by whipping movements in water in much the same manner as mosquito larvae. Because the larvae are abundant, they are an important food item of freshwater fish and other aquatic animals.

LIFE STAGE CHARACTERISTICS

EGG

Adult Chironomidae, soon after emergence from the aquatic pupal stage, swarm, mate, and deposit gelatinous masses of eggs in the water, either at

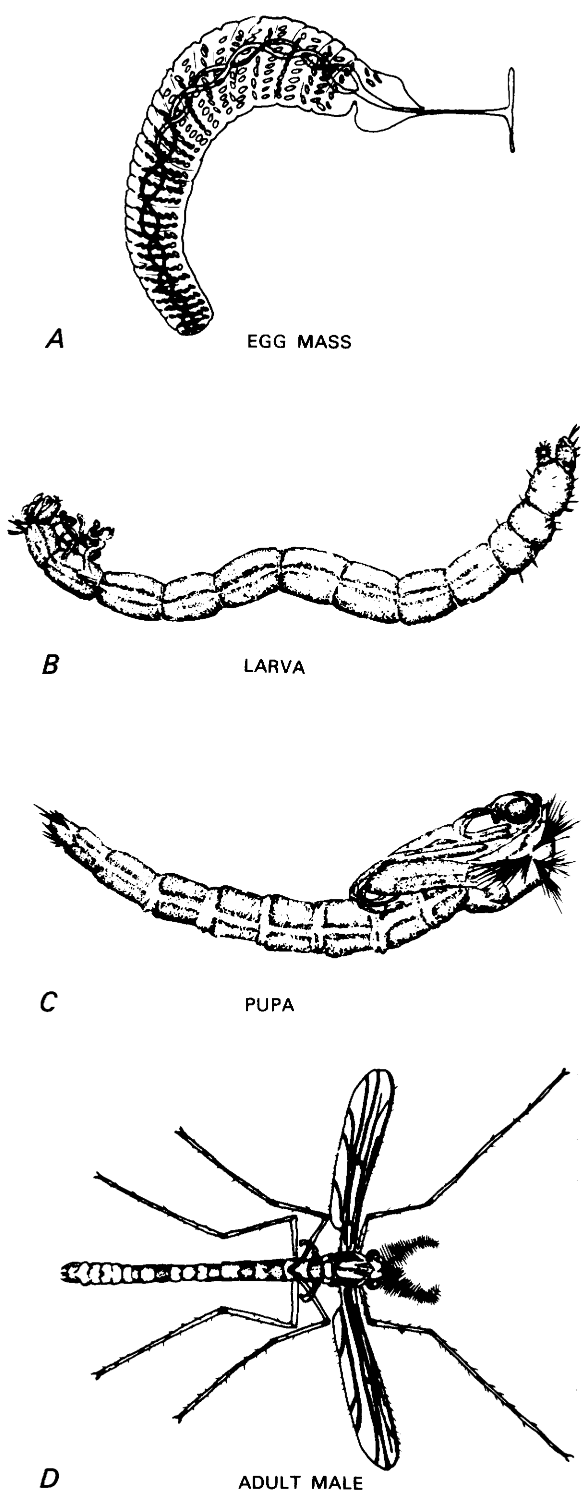

FIGURE 12.—Egg mass and adult male (note plumose antennae of *Chironomus plumosus*) and larvae and pupa of *Chironomus tentans* (modified from Borror and others, 1976). Shown about five times life size.

the water surface, or attached to aquatic vegetation or other firm substrata. By absorbing water, the eggs expand to several times their orginal size (fig. 12*A*). The length of time between egg laying and hatching is probably temperature-dependent and related to the overall length of the life cycle. Ward and Cummins (1978) reported that egg masses of *Paratendipes albimanus* had a diameter of about 4 mm and contained 250–450 eggs.

LARVAE

Larval chironomids grow by molting or shedding the old skin. Most of the actual increase in larval size occurs during the short time following the molt when the exoskeleton is soft. The interval between molts, when the larva feeds and stores energy for the next molt, is called an instar. Most chironomids have four larval instars, but some have five. Mature larvae range in length from 2–30 mm, depending partly on the species and partly on environmental factors. Newly hatched larvae of the first instar are difficult to collect because they are planktonic, until a suitable habitat is located. When a suitable habitat is found, the first or second instar establishes a mode of life that usually is unchanged until pupation. Different species have different modes of life. Some are case builders, others burrowers, crawlers, or swimmers. Case builders feed by creating a flow of water and suspended food into the case by body undulations. Free-living species spin loose nets which trap floating detritus. Burrowers feed on sedimented material using their burrow or nest as a retreat. The crawlers move through masses of algae or live under stones in water where they graze on attached algae. The active swimmers are predators.

All larvae move from place to place, some only occasionally and others quite often. This movement normally occurs at night when they are less vulnerable to being eaten by fish. Chironomids of lake environments move vertically in the water column, depending on species or conditions. Periodic movements occur at low water when chironomids leave their burrows or nets and move into deeper water. Little is known about why they move, travel, or orientate, but it is possible that movement is related to feeding or avoiding adverse environmental conditions, such as low-oxygen concentrations. In rapidly flowing waters, chironomid larvae commonly are collected in drift samples.

PUPA

The transitional stage between larva and adult is called the pupa (fig.12*C*). Pupae of chironomids are either free living or sedentary. The free-living pupae are strong swimmers. Most sedentary pupae are protected by some sort of case, but others lie free on the substrate. Sedentary pupae pupate inside the last larval instar case or sometimes inside cases left by other larvae. Compared to the larval state, the duration of the pupal stage is brief, ranging from a few hours to a few days. Because of this, the pupal stage has been little studied.

When a mature pupa receives the proper stimulus, it moves to the surface of the water, sheds its pupal skin, and emerges as an adult. During the swimming ascent to the water surface, pupae are vulnerable to predation. Recently, shed skins of chironomid pupae have been used successfully for water-quality monitoring (Coffman, 1973; Wilson and McGill, 1979). Proponents of the method maintain that for large rivers, sampling of shed pupal skins provides a simpler and more quantitative indication of the chironomid fauna for biological assessment of water quality (Wilson and McGill, 1979).

ADULT

The adult emerges from the pupal skin at a split in the top of the thorax and emergence is normally a rapid event, occurring 10–30 seconds or, at most, several minutes. The adult is able to fly almost immediately. The adult stage generally lasts several weeks during which time mating and egg laying take place. The adults have nonfunctional mouth parts and do not feed. See Oliver (1971) for more details of chironomid life histories. The duration of each life stage is summarized in fig. 13.

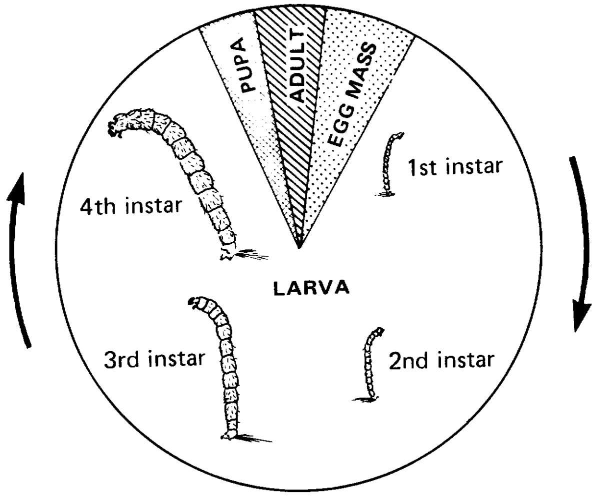

FIGURE 13.–Life cycle of the Chironomidae showing approximate relative duration of each stage (modified from Wilson and McGill, 1979).

KINDS AND DISTRIBUTION OF CHIRONOMIDAE

The Family Chironomidae has seven subfamilies[1], each having characteristic environmental requirements (fig. 14) which may be summarized as follows:

Diamesinae. Found in cold flowing water; predominate only in polar, alpine, and glacial streams.

Orthocladiinae. Exists in the widest range of habitats, but primarily in cold flowing waters; predominate from subpolar through temperate waters; decrease in abundance, but not uncommon in warm waters; the only subfamily with terrestrial species.

Chironominae. Found mostly in warm, standing waters, but do occur in cool, running water; predominate in sluggish, low-oxygenated waters from subpolar regions through temperate climates and into the tropics.

Tanypodinae. Occurs in warm, standing waters and in sluggish to rapidly flowing streams from the subpolar regions into the tropics, except in oxygen-poor waters.

Podonominae. Uncommon; restricted to cold Arctic and alpine streams.

Telmatogetoninae. Uncommon; occurs principally in tidal pools and near brackish water.

Aphroteninae. Rare; restricted to swift mountain streams in the southern hemisphere (Brundin, 1966).

Diamesinae and Orthocladiinae, normally found in rapidly flowing, cold, well-oxygenated waters, are considered primitive. Morphological differences of adults are easily recognizable, but the larvae and pupae are very similar in appearence. The larvae of Diamesinae species have rings called annuli on the third antennal segment (fig. 15*A*). Diamesinae and Orthocladiinae (fig. 15*B*) differ from the Chironominae by not having lines or striae on the paralabial plates (fig. 15*C*); if

[1]Insect families always have the latin ending 'idae' and subfamilies 'inae.

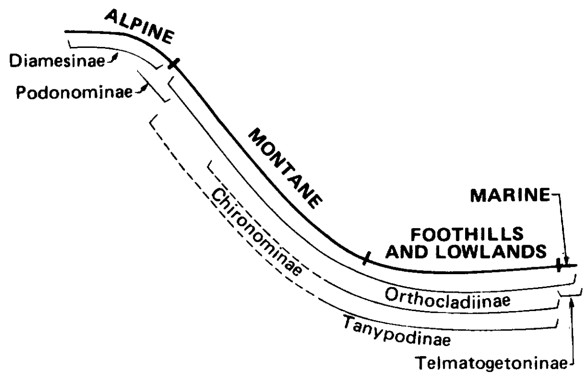

FIGURE 14.–Generalization of Chironomidae subfamily distribution in aquatic habitats of the Northern Hemisphere Temperate Zone.

paralabial plates are present, they are bare or may have bristles. Chironominae and Tanypodinae, which characteristically inhabit pools, lakes, and other types of standing waters, are considered to be less primitive than the other subfamilies. However, some genera of Tanypodinae have readapted to rapidly flowing waters (Brundin, 1966). Larval Tanypodinae, most of which are predaceous, are distinct from the other subfamilies in having long retractile antennae and a lingua instead of a labial plate (fig. 15*D*).

SOME ENVIRONMENTAL FACTORS AFFECTING LARVAL CHIRONOMIDS

Chironomid subfamilies have well-known broad environmental requirements. Groups within the subfamilies have more specific requirements for water velocity, water temperature, dissolved-oxygen content, and type of substrate. Because of specific habitat requirements of the various species, chironomids show promise as indicators of types of streams or lakes (Saether, 1975).

Larvae of different chironomid species have different tolerances to low dissolved-oxygen concentrations. Some species characteristically live in areas of low dissolved oxygen, whereas others can survive only at high concentrations of dissolved oxygen. The Chironominae and Tanypodinae subfamilies have most of the species that can tolerate low concentrations of dissolved oxygen. Some tube-building Chironominae can withstand prolonged periods of anaerobic conditions in nature. The chironomids that possess hemoglobin are found commonly in low dissolved-oxygen environments, but they also can be found in well-oxygenated streams where pockets of low dissolved oxygen occur in sandy and muddy areas. Diamesinae and Orthocladiinae normally require dissolved-oxygen concentrations greater than 4.0 mg/L.

Most Chironomidae complete their development in temperatures between 0°C and 32°C. However, some Chironominae, Tanypodinae, and a genus of Orthocladiinae can live in waters up to 40°C (Curry, 1965). The author has found chironomids in supercooled mountain streams at temperatures slightly below 0°C. Generally, development of larvae is more rapid at higher temperatures, although mature larvae are smaller than larvae that have developed in cold water. In tropical streams, Syryamaki (1965, cited in Oliver, 1971), reported a species of Chironominae which completed development from egg to adult in 10–12 days where the temperature remained above 30°C.

Chironomids are found most commonly in waters that range from pH 6.0–8.0, but they can be found in waters of pH 5.0–9.0. Some Chironominae reportedly survive in waters with pH as low as 2.3–3.2, but the larvae were unable to complete development (Harp and Campbell, 1967). Roback (1974) reported that chironomid larvae were the most common dipteran larvae capable of tolerating many chemical extremes (table 1).

CURRENT RESEARCH

Aquatic biologists in North America and Europe are seeking to increase the understanding of the role of widespread insects in biological community structure and function. Both pristine and stressed environments are being studied. Improved knowledge in these areas should enhance the ability to apply chironomid data in the evaluation of environmental quality. Further advances in ecological research with the chironomids are contingent on improved capability for identifying larval species. This is as true today as 10 years ago when Hynes (1970) wrote: "We know very few of the life histories of the ecologically very important Chironomidae. This is mainly because of our inability to identify the larvae."

SUMMARY

Chironomid larvae can be found in virtually every aquatic habitat. They are among the most diverse groups of insects in the world. Almost every benthic invertebrate sample contains

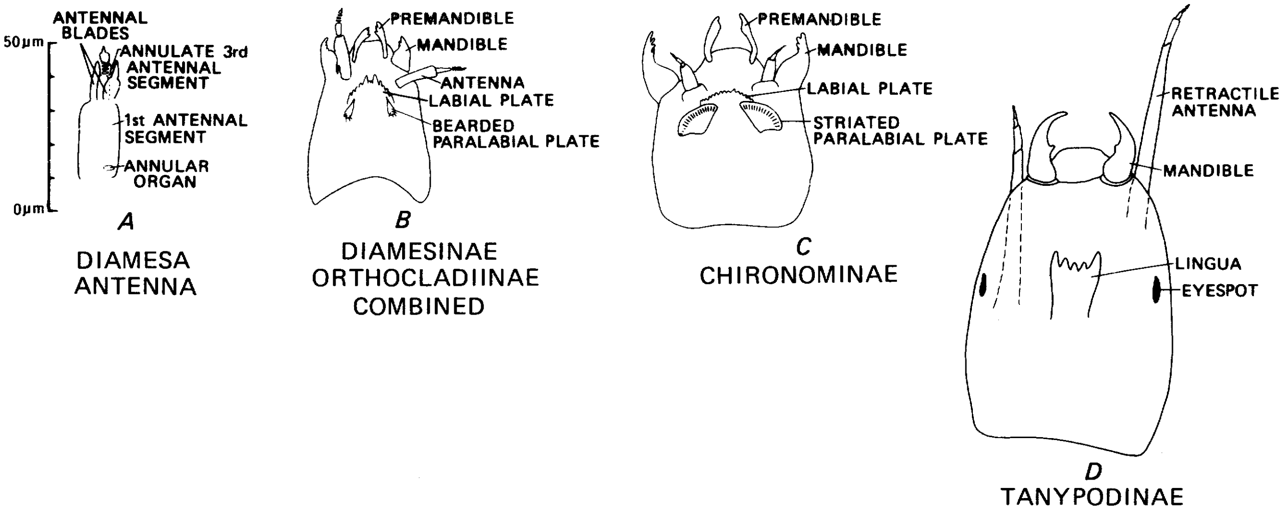

FIGURE 15.—Head capsules and an antenna from the four principal subfamilies of Chironomidae (modified from Tilley, 1978, 1979).

TABLE 1.—*Dipteran representatives of common chemical extremes in water (modified from Roback, 1974)*

Parameter	Chemical extremes	Larval dipterans found		Chironomid subfamilies represented
		Chironomids	Other Dipteran	
pH	8.5	13	0	All
pH	4.5	14	1	No Orthocladiinae
Alkalinity	210 mg/L	14	1	Few Orthocladiinae
Chloride	1,000 mg/L	14	1	Few Orthocladiinae
Brackish water	--	6	1	All*
Iron	5.00 mg/L	3	0	Chironominae only
Dissolved oxygen	4.00 mg/L	13	2	All*
High hardness	--	9	4	All*
Sulfate	400 mg/L	8	2	No Orthocladiinae
Biochemical oxygen demand	5.9	7	1	All*
Biochemical oxygen demand	10	2	1	Chironominae only

*Not enough data are available for Diamesinae and Podonominae. Roback's (1974) data were for samples primarily from mountainous or lowland eastern United States streams. Telmatogetoninae are represented poorly and no Aphroteniinae are found in the northern hemisphere. Mesh size of samplers was not indicated in Robacks' report. If mesh size is too large (openings greater than about 200 µm), most small forms of Chironomidae will be missed in sample collections.

chironomid larvae, and the more intensive the sampling, the greater the chironomid fraction in both numbers and species. The major part of the chironomid life cycle is the larval stage during which all feeding, development, and growth occurs. This accounts for the fact that the larva is the most abundant chironomid life stage found in benthic invertebrate samples. Chironomid pupal skins, which are not as prevalent in benthic invertebrate samples, can be used to determine much of the chironomid part of the benthic invertebrate fauna.

Chironomid subfamily distribution is predictable and, depending on the information supplied, aquatic biologists often can predict which groups will be found in given conditions of waterflow, geographical location, and substrate type. The family Chironomidae includes many species of great variety with respect to environmental requirements and tolerances to stress. Because the requirements and tolerances cover such a wide range of water quality, the Chironomidae as a group have proven to be valuable biological indicators of environmental quality. In fact, any detailed ecological study of surface waters requires a knowledge of the chironomids present.

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Influences of Water Temperature on Aquatic Biota

By Ray J. Hoffman and Robert C. Averett

ABSTRACT

Aquatic organisms, except for birds and mammals, have body temperatures that are similar to the temperature of the water in which they occur. As water temperature changes, so does an organism's body temperature. Each plant and animal has minimum and maximum temperatures below and above which the organism cannot tolerate. An organism can acclimate to temperature changes.

INTRODUCTION

The amount of heat in water is a familiar and somewhat exacting requirement for most of us. We are instantly aware of a water temperature that is too high or too low for bathing, swimming, or drinking. Because we obtain our water for everyday use from controlled systems, we can adjust quickly the water temperature at the tap for the desired use of the water.

In nature, however, our options for adjusting or altering water temperature are extremely limited. Once the temperature of a stream or lake rises or drops to a particular level, any change to another temperature is a slow process. Aquatic organisms either must adapt to the temperature of the environment, seek an area having a more compatible temperature, or die.

With the exception of aquatic birds and mammals, all aquatic organisms are "cold blooded," meaning that their body temperatures varies directly with the water temperature. A rise in water temperature is followed by a rise in body temperature. The scientific adjective to describe this physiological temperature-environment process is "poikilothermic." The opposite of poikilothermic is "homothermic." All birds and mammals (including man) are homothermic animals. Regardless of the air or water temperature, birds and mammals can maintain an almost constant body temperature through a rather wide environmental range. They adjust for air temperature changes by shivering, if it is too cold, and by perspiring, if it is too warm. When the temperature range is extreme, and the body can no longer adjust, death occurs. The body temperature of an aquatic poikilothermic organism simply varies with the temperature of the water. But, as with homothermic animals, there are definite upper and lower temperature limits beyond which the organism dies.

While we often consider water temperatures only as a simple descriptive factor, it is an extremely important environmental factor for aquatic life. This paper discusses some of the influences of water temperature on aquatic life. Most of the research on the influence of temperature on poikilothermic animals has been with fish, and much of the discussion that follows will use fish as examples. The processes involved, however, are similar for all poikilothermic animals, and as will be seen, plants exhibit some of the same physiological responses to temperature as do animals.

WATER TEMPERATURE AS A CONTROLLING FACTOR

A controlling factor is an environmental condition that acts upon the metabolism (bodily functions) of the organism, but does not result in death. A controlling factor may cause sufficient discomfort, or shift the energy and material resources of an organism towards a wasteful direction. One metabolic process common to all organisms, and continuous throughout life, is respiration. In the respiratory process, organisms remove oxygen from the environment and use it to oxidize foodstuffs for energy and material. The respiration rate (oxygen uptake per unit time) of aquatic poikilotherms increases, with increasing water temperature, until such time as the lethal temperature for the organism is reached. The result is an interesting paradox; an organism needs more oxygen for respiration at higher temperatures, but the solubility of dissolved oxygen in the water is reduced as the water temperature increases, resulting in less oxygen being available for the increased respiratory need.

In his study of the metabolic rate of sockeye salmon, Brett (1965) found that the standard metabolism (respiration or dissolved oxygen uptake of a resting poikilotherm) was 45 milligrams of oxygen per kilogram body weight of salmon per hour (mg O_2/kg salmon/hr) at 5°C and 80 mg O_2/kg salmon/hr at 15°C. This is almost a twofold increase in oxygen consumption for a 10°C increase in water temperature and corresponds well with the Q_{10} law of biochemistry which states that for each 10°C increase in temperature, the reaction rate (here, oxygen consumption per unit time) will double to triple. In a similar experiment, juvenile coho salmon increased their oxygen consumption from 0.15 mg O_2/kg salmon/hr at 8°C to 0.35 mg O_2/kg salmon/hr at 17°C, a rate increase factor of about 2.1 per 10°C increase in water temperature (Averett and Brockson, 1970). There are numerous examples with poikilothermic organisms where the respiration rate as a function of temperature follows the Q_{10} law.

Although respiration can be measured indirectly by oxygen uptake, it is most importantly an energy and material utilization process. Thus, when the respiration rate increases, the amount of energy and material that the organism needs for its life processes also increases. The ratio between respiration rate and the energy and material requirement is not necessarily 1:1, but both increase and decrease together. The respiratory rate also varies with seasonal change, as well as with the weight of the animals. Small animals (including the young of large animals) have much higher respiration rates per unit weight than larger animals.

The relations between standard metabolism, water temperature, season, and weight of coho salmon are shown in figure 16. In this study, calories, a unit of energy measurement (1 calorie is the amount of heat energy needed to raise the temperature of 1 gram of water 1°C) was used in place of oxygen uptake. Note that at 5°C, the smallest fish (diamond-shaped symbol) had twice the standard metabolism of the larger fish (triangle-shaped symbol). Brett (1965) determined the relation between temperature and maximum swimming ability of sockeye salmon. The energy used by the fish was measured in calories (fig. 17). The bottom curve in figure 17 is the standard metabolic rate, and the top curve is the active metabolic rate, or the caloric uptake of the fish when swimming at maximum speed. Brett termed the difference between the top and bottom curves as the "scope of activity" at a given temperature. The optimum temperature for maximum swimming activity for the sockeye salmon was 15°C. The scope of activity concept has obvious practical and physiological implications in designing fish passage systems over dams, and in determining the well-being of aquatic organisms as a function of water temperature, as well as the production of fish for food.

Thus far, water temperature as a controlling factor of aquatic life has been related to standard metabolism and activity. But, if an organism is to survive, it must do more than carry out standard and active metabolism; it also must capture and digest food, rid itself of undigested food and other wastes, and grow. A simplified formula for these processes can be written as:

$$Q_c = Q_s + Q_d + Q_a + Q_w + Q_g$$

where: Q refers to material and energy intake and
c = total food consumed
s = standard metabolism
d = digestion and movement of food throughout the body
a = activity
w = waste material (feces and urine)
g = growth.

It is interesting as well as important to note that the Q_g term (growth) cannot take place, that is the organism cannot grow, until all of the other energy and materials terms (Q_s, Q_d, Q_a, and Q_w) are satisfied. It also is important to note that each term in the above formula is temperature dependent. When this is realized, it is not difficult to understand why temperature is the master controlling factor of life in the aquatic environment.

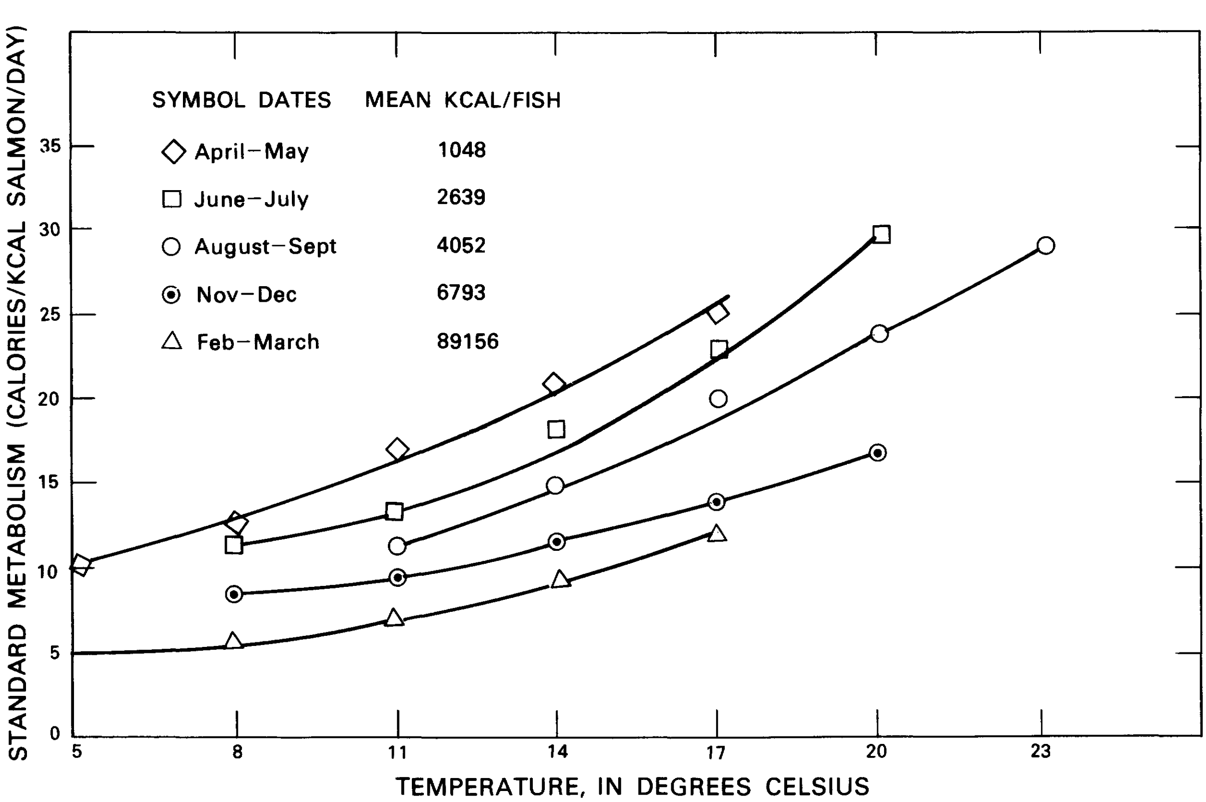

FIGURE 16.–Seasonal metabolic rates of coho salmon as a function of water temperature (from Averett and Brockson, 1970).

Water temperature also can influence the reproductive success of aquatic organisms. Bolke and Waddell (1975) reported that after the completion of Flaming Gorge Dam on the Green River, Utah-Wyoming, the annual water temperature range and the season of high and low temperatures in the river downstream from the dam were altered greatly. Prior to closing the dam, the average annual water temperature in the Green River downstream from the reservoir ranged from just above 0°C–19.5°C as compared to 3.5°C–10°C, since closure of the dam. Moreover, before closing the dam, the low water-temperature period was December to February, and the high-water temperature was July. Since closure of the dam, the low water-temperature period has shifted to March and the high-water temperature period is November. These changes in the water temperature regime of the river downstream from the dam resulted in a marked decrease in the reproductive success of trout. A multiple release device has since been installed in the reservoir so that water having a temperature corresponding to that of the river before dam construction can be released.

While the above discussion has been concerned with animals, McCombie (1960) illustrated the effect of temperature on the growth of the green alga, *Chlamydomonas reinhardi* (fig. 18). He varied the water temperature, but kept light and nutrients the same. McCombie noted that regardless of the light intensity, the upper lethal temperature for this alga was 35°C. The optimum temperature for growth at all three light intensities and nutrient concentrations was between 25°–30°C.

Bacteria are the master decomposers (oxidizers) of organic matter in nature. They rapidly convert organic wastes and other materials to carbon dioxide, water, and more bacterial cells. Like other poikilothermic organisms, their respiration rate and hence oxidation rate of organic matter increases with rising water temperatures. Thus, the oxygen demand of warmer waters is almost always higher than that of colder waters. For example, in winter, organic material entering a stream may be

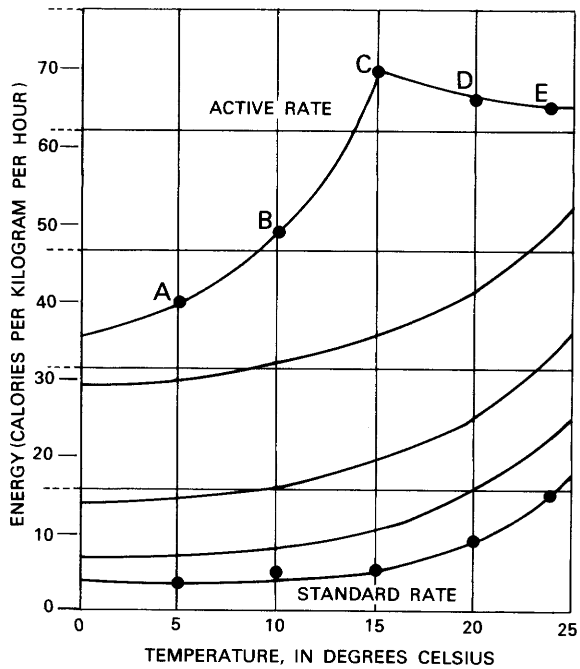

FIGURE 17 – Relation between basal (standard) metabolism and active metabolism at varying temperatures (modified from Brett, 1965).

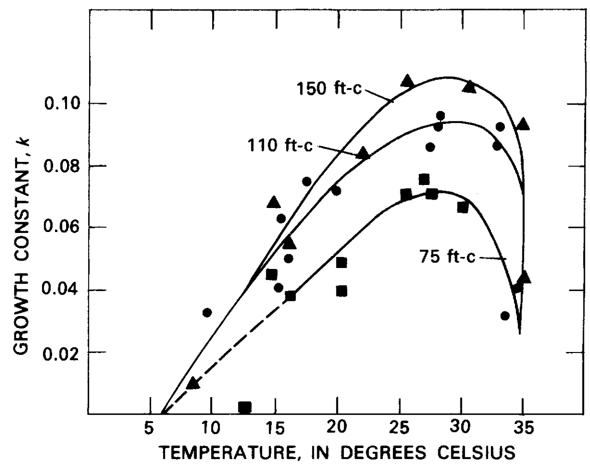

FIGURE 18 – Relation between specific growth rate (k) of the alga, *Chlamydomonas reinhardi*, and water temperature, with constant nutrient concentrations and light intensities of 75, 110, and 150 foot-candles (from McCombie, 1960).

transported a considerable distance before it is oxidized completely by bacteria. In summer, bacteria may oxidize the same amount of organic matter close to its point of entrance to the stream.

WATER TEMPERATURE AS A LETHAL FACTOR

The temperature range within which aquatic poikilotherms can live is often relatively narrow. This range, however, varies with the acclimation temperature; that is, the temperature to which the animal has become accustomed over a period of time. For example, Brett (1956) found that if chum salmon were acclimated at 5°C, their lower lethal temperature (the lowest temperature causing death) was 0.2°C, or just above freezing. The upper lethal temperature (the highest temperature causing death) was 21.8°C. If the salmon were acclimated at 20°C, their lower lethal temperature was 6.5°C, and their upper lethal temperature was 23.7°C. By changing the temperature of acclimation, Brett found that the overall temperature range of the chum salmon was from 0.2°–25°C.

Acclimation to a given temperature is a time response that varies from about 3–60 days with aquatic poikilotherms. In nature, aquatic organisms usually are able to acclimate to high and low temperature extremes because the water temperature in lakes and streams normally changes slowly because of the high heat capacity of water. We would expect, then, that an aquatic organism would have a definite seasonal lethal temperature. This is exactly what Brett (1964) found when he determined the lethal temperature of the bullhead from Lake Opeongo, Ontario (fig. 19). In August, when the lake water was warmest, the upper lethal temperature for the bullhead was near 36°C. In late October, immediately before ice formation and in May immediately after ice breakup, the two coldest water periods in the lake, the upper lethal temperature was near 29°C. There is, then, no single upper or lower lethal temperature, but rather a changing lethal temperature associated with the temperature of acclimation. We can relate these two temperature events for the chum salmon and bullhead as shown in figure 20, taken from Brett (1956). Note that the bullhead, a warm-water fish, has a much wider range than the salmon, a cold-water fish.

Of timely concern is what happens to aquatic poikilotherms, if there is a rapid change in the water temperature of their environment. Such events happen with the shutdown of power plants that release cooling water to rivers or lakes, or with release changes from the top or bottom of a reservoir. A study by Doudoroff (1942) provided in-

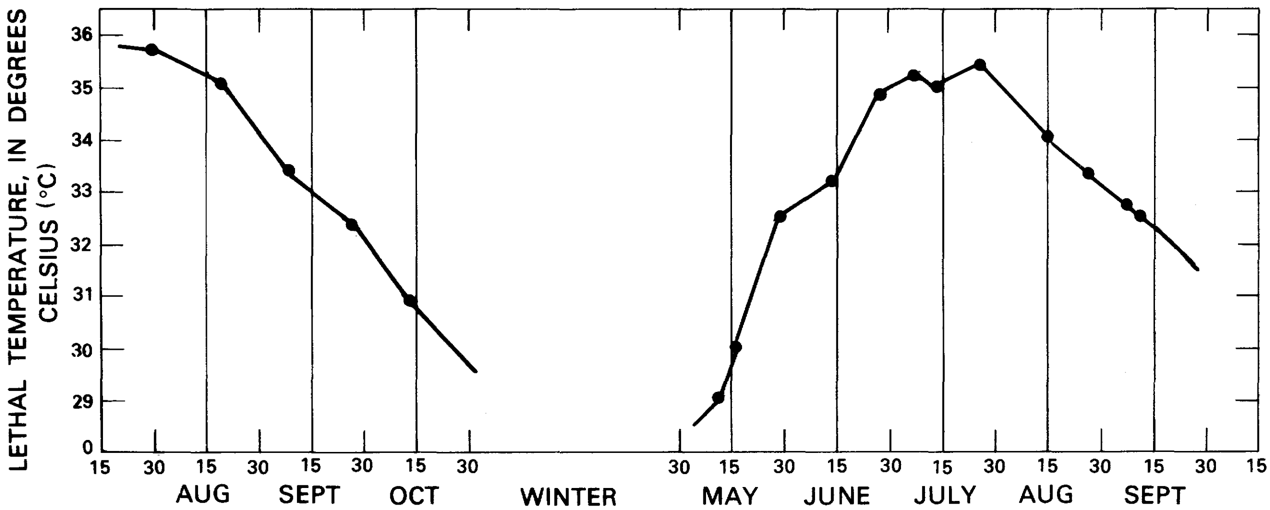

FIGURE 19. – Upper lethal temperature as a function of temperature for the bullhead. Note how the upper lethal temperature corresponds with expected seasonal water temperatures (from Brett, 1964).

sight as to the time required for an organism to acclimate to a rapidly rising or lowering water temperature. Doudoroff determined that the marine greenfish acclimated rapidly to rising water temperatures, becoming fully acclimated in 3–10 days. In contrast, the greenfish acclimated slowly to falling temperatures, becoming fully acclimated only after about 30 days. What this means is that a rapid drop in the water temperature is

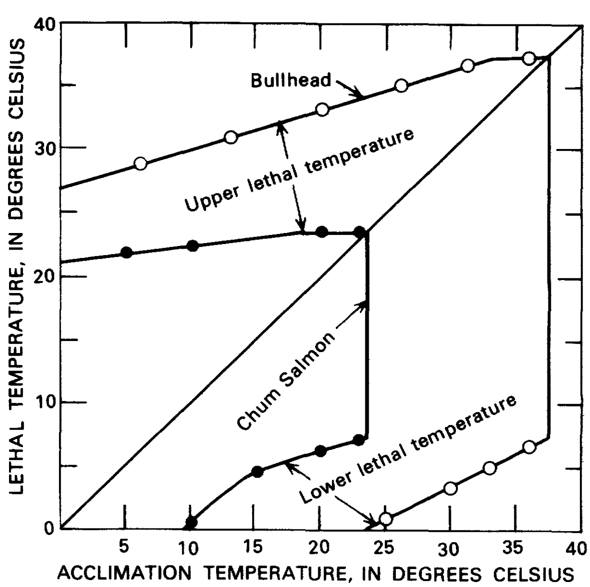

FIGURE 20.—Relation between acclimation and lethal temperatures for the chum salmon, a cold-water fish, and the bullhead, a warm-water fish. Note that as the acclimation temperature increases, the upper lethal temperature also increases (modified from Brett, 1956).

likely to be more costly, in terms of aquatic life, than is a rapid rise in the water temperature. We know that "chill" or "cold death" in aquatic life is a common event. As a result, this is presently a field of active research.

There is a final consideration of the toxic effects of water temperature that frequently is ignored. It is the uptake of lethal amounts of toxic materials by aquatic organisms because of increased respiratory rates resulting from an increased water temperature. For a material to be toxic to an animal, it must enter the bloodstream in a quantity sufficient to stop metabolic processes. With fish and some aquatic insects, oxygen, as well as most toxic materials enter through the gill tissue. Potentially toxic materials in water may be in such low concentrations that during low water temperatures the animal would not accumulate enough toxin in its bloodstream to cause death. But, if the water temperature rises, respiration increases and more oxygen, as well as more of the toxic material, is passed through the gill tissue and into the bloodstream. Thus, a rising water temperature can be an insidious cause of death, even below the upper lethal temperature limit.

Many investigators fail to consider that an alteration in the temperature regime of a river or lake can have a profound influence on the aquatic biota in the system, either by increasing metabolic rates and, hence, energy and material utilization, or by causing death. Alteration of the temperature regime can have significant economic consequences in areas where commercial or sport fisheries are important. Moreover, water temperature may influence decomposition and the assimilative capacity of water to handle waste materials. Such temperature influences are of great significance in the management of rivers, lakes, and estuaries.

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Stream Channelization: Effects on Stream Fauna

By Susan S. Hahn

ABSTRACT

Stream channelization, the straightening of stream meanders, results in loss of streambank vegetation, increased water temperature and turbidity, change in water velocity, change in size and stability of substrates, and loss of shelter. These changes affect the distribution of fishes and benthic invertebrates.

INTRODUCTION

In recent years, the subject of channelizing streams has created much controversy because of its reportedly adverse effects on the environment and its widespread use in both large and small watersheds. Stream channelization commonly is used for controlling floods, improving navigation, relocating streams for highway construction, and draining wetlands to increase agricultural production. When a stream is channelized, it is converted into a wide, straight ditch temporarily devoid of streamside vegetation. The channel is widened, deepened, and cleared of obstructions to allow for greater stream discharge than could be accommodated by the natural channel. The streambanks often are reinforced with streamfill, concrete, stones, or similar riprap. Although research on the ecological effects of stream channelization has been limited in the past, an increasing number of studies have confirmed earlier evidence of biological damage caused by channelization.

BASIC CONCEPTS GOVERNING STREAM SYSTEMS

The physical nature of streams has been described as a continually readjusting complex of interrelated variables: discharge, slope, width, depth, current velocity, channel resistance, and sediment characteristics which exist in "conservative dynamic equilibrium" (White, 1973). That is to say, a stream is changing continually and striving toward a steady state in which there is a minimization of work and an equalization of energy expended along its length (Leopold and others, 1964).

A natural stream also is influenced by the weather, climate, and geology of its watershed. It will meander to a greater or lesser extent creating pools and riffles, variable current velocities, and depths. The substrates with the aid of channel obstructions provide habitat diversity for fishes and benthic fauna. A stream in equilibrium will maximize the total number of potential biological niches and, therefore, biological diversity along its length (Curry, 1972).

The many kinds of aquatic organisms that inhabit streams are woven into a net-like relation with the physical and chemical environments. Many organisms have evolved functional adaptations for living in a specific microhabitat (for example, riffle or pool) within the stream. Each species has a particular set of optimal conditions–water temperature, current velocity, food, shelter, dissolved oxygen, and so on–that insures its maintenance. Changes in the conditions place stress on a species and, depending on the range of tolerance for each stress, will limit its reproduction, growth, density, and survival (Lynch and others, 1977).

BIOLOGICAL IMPLICATIONS OF CHANNELIZATION

Stream channelization, by definition, results in a manmade energy-imbalanced system which is followed by a number of physical and biological changes. It is important to point out that streams are complete systems and that the response to an imposed alteration varies from watershed to watershed. The impact on stream biota depends largely on the severity and extent of channelization and the meteorological and geological conditions of the particular watershed. The biologically important physical changes that result from channelization include water temperature, turbidity, and current velocity; decreases in riparian vegetation, variable water depths, and variable current velocity; and changes in the size and stability of the substrate.

INCREASED WATER TEMPERATURES

The canopy of trees and bank vegetation that normally provide shade to the stream is removed when a stream is channelized. The exposure results in higher water temperatures and increased amplitude of daily temperature fluctuations, particularly during the warmer months. Hansen (1971) found that in channelized stream sections, maximum daily water temperatures averaged 1.3°C lower than in the unchannelized sections of Little Sioux River, Iowa, during July.

BIOLOGICAL IMPLICATIONS

Changes in water temperature have an important effect on the growth rates and the physiological state of fishes, particularly in relation to their resistance to diseases. Each species of fish has upper and lower lethal limits. The brook trout, for example, is extremely sensitive to warm temperatures and begins to show signs of stress at temperatures above 21.1°C (Lynch and others, 1977).

Temperature is related inversely to dissolved oxygen; therefore, an increase in temperature will bring about a decrease in dissolved oxygen, and under certain conditions, the decrease can have detrimental effects on certain species of fishes. Changes in temperature also affect the hatching time of eggs, fish migration, emergence of aquatic insects, and indirectly affect the overall productivity of the stream.

INCREASED TURBIDITY AND SEDIMENTATION

Increased turbidity and sedimentation occur during and immediately after a stream is channelized. The condition often is temporary but can be long term, depending on the prevailing conditions. The process of cutting stream meanders and clearing the stream channel increases the water velocity and the capacity of the stream to scour and transport sediments. Erosion of the streambed and streambanks, thereby, causes higher turbidity. This condition will continue until an equilibrium is attained and the slope is reduced to approximate the original slope (Henegar and Harmon, 1971). Investigators have reported turbidity increases up to 31.2 percent in channelized sections, compared to unchannelized sections (Hansen, 1971). The severity of turbidity depends on the slope of the stream, discharge, depth of flow, and the erodability of the soils (Apmann and Otis, 1965).

BIOLOGICAL IMPLICATIONS

The direct effects of increased turbidity on fishes include inflammation of gill membranes, greater probability of infection, and reduction of the visual feeding range.

The effects of increased turbidity on the fishfood organisms and primary productivity are more harmful than the direct effect on fishes. Increased turbidity increases drift rates in some invertebrate organisms (Pearson and Franklin, 1968) and reduces their survival. Deposition of suspended sediments on the streambed is particularly harmful to benthic invertebrates adapted to clinging to rock substrate because it destroys their habitat as well as their food sources of periphyton and attached micro-organisms. Sedimentation also eliminates potential spawning beds for fishes because interstitial spaces between stones become clogged with fine sediment, resulting in suffocation of eggs and fry, or the loss of such habitat.

Turbidity interferes with heat and light transmission, thereby interfering with photosynthesis in phytoplankton and periphyton–the primary producers of the stream ecosystem.

INCREASED CURRENT VELOCITY

An increase in current velocity usually occurs as a result of straightening stream meanders, and deepening and clearing stream channels. Slope is increased in the straightening process and streamflow resistance is minimized by the removal of channel obstructions.

BIOLOGICAL IMPLICATIONS

Current velocity is important to fishes because of its effect on eroding and grading bed materials, which directly affects the density of fishfood organisms. Increased current velocity also affects the amount of drifting benthic invertebrates and indirectly affects the availability of food for fishes. Lewis (1969), in a study of the physical factors influencing fish populations in pools of a trout stream, showed that current velocity and shelter were the most important physical factors influencing trout densities.

Current velocity also plays a major role in the spawning success of fishes. Many species of salmonids (that is, trout and salmon) will spawn only within a narrow range of current speeds (White, 1973). The survival of eggs in gravel beds is highly dependent on adequate currents to maintain high levels of oxygen in the intragravel water.

REMOVAL OF RIPARIAN VEGETATION

Removal of riparian vegetation has detrimental effects in addition to the increase of water temperature and the decrease of shelter for fishes. Leaf litter or "allochthonous organic detritus" serves as an important source of food for aquatic invertebrates, particularly in the headwaters. Undisturbed headwater streams are shaded heavily and a group of benthic invertebrate species called shredders, adapted to converting large pieces of leaf litter to small particulate matter, are dominant in the community. The small particles produced by the shredders are utilized in turn by collector-type benthic invertebrates further downstream (Cummins, 1975). Extensive channelization in headwater streams (stream orders 1–3) removes an important source of food for benthic invertebrates and can have adverse effects on the total energy input and productivity of the entire stream ecosystem.

The removal of riparian vegetation also may reduce the density of terrestrial insects, which normally provides an important source of food for fishes (Lynch and others, 1977).

REMOVAL OF STREAM OBSTRUCTIONS

One of the detrimental effects of channelization on fish populations is the decrease of shelter following removal of large boulders, logs, encroaching vegetation, deep pools, and undercut banks, which characterize natural meandering streams. In large rivers characterized by finer silt-laden streambeds, natural shelter is provided by plant beds, steep sides of the stream channel, mudbanks, and tree roots.

BIOLOGICAL IMPLICATIONS

Shelter is important to fishes for protection from predators, avoidance of excessive currents, and maintenance of a stable fish population. Fishes spend a large part of their time in dead-water areas behind large boulders, logs, or in deep pools to avoid excessively fast currents which consume much energy (Cummins, 1972). The absence of shelter stresses the fish population and often leads to migration to areas with more suitable conditions. Lewis (1969) determined that shelter was the most important physical factor affecting the densities of brown trout in cold-water streams. Duvel and others (1976) found that while all size classes of trout were collected at natural sites, only small trout were found in channelized stream sections that were devoid of deep pools, boulders, and undercut banks. The lack of shelter that is important to fishes has less effect on benthic invertebrates. Large obstructions are important to bottom fauna by affecting current velocities or providing surface attachment areas in depositional (silty streambed) streams. The absence of pools in channelized reaches also may affect the occurrence of typical pool benthic invertebrates and thereby decrease the diversity in the stream reach.

CHANGE IN THE SIZE AND STABILITY OF SUBSTRATE

The removal of channel obstructions and the absence of meanders contribute to a relatively uniform substrate particle size in channelized streams. This is accompanied by unstable, shifting substrates, particularly in the mainstream.

BIOLOGICAL IMPLICATIONS

The nature of the substrate is particularly important to invertebrates that live on or in the streambed. Substrate particle size represents a type of benthic microhabitat which is occupied by characteristic benthic assemblages. Riffle habitats are inhabited by invertebrates adapted to surviving in the current by clinging to hard surfaces or avoiding the current by hiding beneath rocks, whereas pools and slow rivers harbor organisms adapted for burrowing and crawling over soft, muddy substrates (Moon, 1939). Channelized reaches lack the substrate diversity found in pools and riffles of a natural reach and can be expected to yield fewer kinds of benthic invertebrates.

There is some evidence that density of benthic fauna is influenced by the size of the bottom material, with rocks between 45- and 90-mm mean diameter yielding the highest numbers of aquatic insects and larger and smaller rocks having lower insect densities (Lium, 1974).

Another factor affecting the density of benthic invertebrates is the stability of the substrate. Shifting bed material discourages benthic invertebrate colonization. Percival and Whitehead (1929) found fewer organisms on loose stones than on embedded stones.

CHANNELIZATION AND FISHES

COLD-WATER FISHES

There appears to be general agreement among investigators that stream channelization has detrimental effects on cold-water fishes, particularly trout (Whitney and Bailey, 1959; Izarry, 1969). Significant reductions in numbers of catchable trout have been reported in channelized stream reaches as short at 0.40 km (Duvel and others, 1976). Investigators have attributed this reduction to the loss of shelter. Increased water temperature also may stress cold-water fish species.

Documented reports on the effects of channelization on nongame fishes in cold-water streams are sparse and sometimes inconsistent. Elser (1968) found a 100 percent reduction of nongame species in the channelized section of Little Prickly Pear Creek, Montana, whereas Duvel and others (1976) found no deleterious effect of forage fish populations as a result of channelization of six cold-water Pennsylvanian streams.

Moyle (1976) found very little effect on forage fish populations in Rush Creek, California, 4–5 years after channelization. The pit sculpin was the only species of fish that was found in greater numbers in channelized stream sections, as compared to the unchannelized section. The endemic modoc sucker and the trout decreased significantly as a result of channelization. Destruction of habitat was suggested as the most damaging aspect of stream channelization, while the lack of food organisms was of secondary importance.

WARM-WATER FISHES

Warm-water fishes have been reported to respond to stream channelization by a decrease in density and species diversity (Congdon, 1971; Golden and Twilley, 1976; Groen and Schmulback, 1978). Higher order streams like the Missouri River and its tributaries were subject to channelization to improve navigation and agricultural production. Channelization often was severe with a 30–50 percent reduction in stream length, leaving the aquatic habitat severely altered from its natural state. The Chariton River in Missouri, for example, was reduced 55 percent by channel straightening and, in combination with a poorer habitat, resulted in an 87 percent reduction in total standing crop of fishes (Congdon, 1971). Diversity of fishes also decreased from 21 species in the unchannelized reaches to 13 species in the channelized reaches.

Bayless and Smith (1967) found similar results when comparing 29 channelized streams in eastern North Carolina with 36 natural streams. They reported an 80 percent reduction in total standing crop of fishes with very slow recovery over a 40-year period.

CHANNELIZATION AND BENTHIC INVERTEBRATES

Benthic invertebrates are an important source of food for fishes and play an integral role in the trophic structure and function of stream ecosystems. The most important environmental factors governing the density and composition of benthic invertebrates include type of substrate, particle size and stability of substrate, current velocity, water quality (turbidity, dissolved oxygen, pH, and so on), and those factors that directly affect the availability of food–primary production (light, nutrient levels, and so on) and allochthonous organic matter (primarily leaf litter).

There have been conflicting reports evaluating the impact of channelization on benthic invertebrates. In a study comparing the effects of small-scale channelization on fishes and benthic fauna in a California trout stream, a threefold reduction of riffle invertebrate biomass and a decrease in number of species was reported in the channelized section, compared to the natural section 4 years after channelization (Moyle, 1976). Duvel and other (1976), on the other hand, found very little difference in invertebrate density and composition between the natural and channelized reaches in six Pennsylvania trout streams. The authors stated that water quality was good and the presence of cobble (63.5–254 mm in diameter) probably provided an adequate habitat for the benthic fauna.

In channelization studies involving larger rivers, benthic areas were reduced drastically by channel straightening, but only slight adverse effects on benthic invertebrates were reported. Morris and others (1968) and Hansen (1971) found similar invertebrate density and composition in channelized and unchannelized sections. Morris and others (1968) reported a significant difference in biomass of drift organisms between altered sections (6.5 mg/m^3) and unaltered sections (55.1 mg/m^3), whereas Hansen (1971) found the reverse to be true. Hansen stated that higher drift quantities in channelized sections could have resulted from higher benthic production on adjacent riprap areas. Artificial substrates in the same channelized areas yielded greater numbers of invertebrates than in natural areas suggesting a lack of suitable attachment areas in the channelized reach.

A comparison of old channelized, newly channelized, and natural reaches of Luxapalila River, Mississippi, showed that the standing crop of benthic invertebrates was greatest in the natural reach (Stroud, 1977). The natural reach had larger streambed materials than the old or newly channelized segments and this was considered to be an important factor enhancing the quantitative and qualitative abundance of the benthic invertebrate community.

RECOVERY

All streams attain a stable gradient by creating meanders, undercut banks, pools, and so on. Channelized streams are no different. After channelization occurs, the stream eventually will "recover" or seek a natural course dictated by the geology, slope, and discharge. The time required for a channelized stream to fully recover will depend on the particular conditions of the watershed and the degree of alteration imposed on the system.

Tarplee and others (1970), in a study of coastal plain streams in North Carolina, showed that amount of shelter was the most important factor affecting the recovery of fish populations following channelization. Data indicated that an increase in shelter above 15 percent resulted in a marked improvement in habitat quality and fish production. Channelized streams apparently recovered to near natural conditions and the fish population recovered in about 15 years with no channel maintenance. Ecological succession occurred on the stream banks and streambed, resulting in a better habitat for fishes and benthic invertebrates. The authors concluded that the detrimental effects of channelization could be reduced, if more shelter were retained during channelization.

Some studies report short recovery periods following small-scale channelization. Barton (1977), in a study of the short-term effects of highway construction on a small stream in southern Ontario, reported that although there were immediate effects of small-scale channelization on fish populations, the populations soon returned to normal levels after construction. Channelization effects on invertebrate populations were temporary, and recolonization quickly occurred by drifting organisms (Pearson and Franklin, 1975; Duvel and others, 1976). Chisholm and Downs (1978) also reported temporary effects and rapid recolonization by benthic invertebrates after stream channelization.

Other researchers have reported a slow recovery toward natural stream conditions and productivity following channelization. Moyle (1976) found significant reductions in the density of trout and benthic fauna after 4 or 5 years of recovery in short channelized reaches (1.6 km). In cases involving many stream kilometers and severe channel straightening, significant recovery did not take place even after 40–50 years (Congdon, 1971; Stroud, 1977).

SUMMARY AND CONCLUSION

The practice of channelizing streams for a variety of purposes is widespread and currently the focus of controversy. The limited published research has shown that biological damages are unavoidable under existing channelization practices. Channelization involves straightening stream meanders, deepening and widening stream channels, and clearing stream bank vegetation. Other physical changes, increased turbidity, increased temperature, change in current velocity, change in size and stability of substrate, and a loss of shelter can have far-reaching adverse effects on fishes and benthic fauna. Both cold-water and warm-water game fishes are reduced greatly in numbers and composition by direct and indirect effects of channelization. Smaller nongame or forage fishes are less severely affected. Stream recovery in terms of fish productivity depends on the severity of channelization and the physical, geological, and biological conditions of the watershed. Many reports indicate a long recovery period where severe channel straightening and extensive removal of riparian vegetation has occurred, resulting in a drastic reduction of shelter.

Reports on the effects of stream channelization on benthic invertebrates are often conflicting because of the different kinds of substrate involved. There is general agreement that benthic invertebrates are drastically reduced during and immediately after channelization because of increased turbidity and sedimentation. Some studies report long-term adverse effects on benthic fauna, despite good water quality (Moyle, 1976), whereas others report rapid recolonization and complete recovery as quickly as 1 year after channelization (Chisholm and Downs, 1978; Barton, 1977). Benthic invertebrates are sensitive to turbidity and sedimentation, current velocity, substrate type and size, and substrate instability. The specific response of benthic fauna to channelization depends to a great extent on the way that each channelization project alters these factors. Drifting organisms enable rapid recolonization of benthic populations, provided that suitable habitats remain or are recreated after channelization.

Streams are dynamic and complicated systems whose physical, chemical, and biological components are constantly interacting to produce a balanced ecosystem. Each watershed is different, and a physical alteration imposed on each stream system will have varying effects on the biota and on the time required for recovery.

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