WATER POLLUTION BIOLOGY

A LABORATORY/FIELD HANDBOOK

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Preface

SPORADIC, but significant research in water pollution biology occurred well over a hundred years ago in England, France, and Germany. The chlorination of sewage effluent as a health measure in the early 1900s, however, effectively stymied further growth of the discipline. It wasn't until the 1950s in the U.S.A. that an awakening of environmental awareness caused the shift from a public health to an ecological perspective. Criteria and remedial measures to upgrade water quality necessitated biological input. Early investigators such as C. Tarzwell, P. Doudoroff, and R. Patrick mounted what was essentially a four-pronged effort to create methodologies for the interpretation of the biological response to chemical and physical stimuli: (1) indicator organisms; (2) community structure (diversity, dominance, etc.); (3) community function (respiration and photosynthesis); and (4) bioassay and toxicity tests. Since these avenues of study evolved sequentially, it is our intent to direct the student along the same path.

The methods described here have been generally adopted by consulting firms and state and federal water pollution control agencies. The manual, therefore, is applications oriented and is not designed to serve the limnologist. The chemical and physical parameters of an experimental and control station measured in Chapter 1 provide the basis against which the biological data, retrieved from the same stations, in Chapters 2, 3, and 4 are correlated.

As the student refines his/her laboratory techniques, hopefully he/she will also learn that the "parts per million" perspective is limited. While the chemist is capable of rapidly generating prodigious quantities of data, these parameters attain significance only in a biological context, for pollution is fundamentally a biological phenomenon. The chemical inventory provides a precise "roll call" of what could be impinging on or contributing to the aquatic ecosystem. But the presence of a particular chemical in a specific

quantity does not necessarily assure its biological accessibility; it is for the organism to integrate the total stimulus over time. Furthermore, chemical data provide no dimension of time. They only pertain to the sample analyzed.

Probably the most informative data in the assessment of environmental quality are those derived from a competent inventory of the benthic macroinvertebrates. Because of their limited vagility, ubiquitous distribution, and high diversity and abundance, they remain the best indices of water quality. Two areas of expertise must be cultivated before this approach can be implemented. Chapter 2 is devoted to the acquisition of these skills: the identification to the generic level of the major aquatic invertebrate orders and the collection of ecologically and statistically significant samples. The exercises bring students from developing sampling strategies in the laboratory to their application in the field. The retrieved samples (artificial substrates, Surber square-foot samples, etc.) are processed to identify index organisms and derive abundance and diversity values.

Having addressed community composition and structure, the perspective evolves, in Chapter 3, to an investigation of community function. Students will focus on net and primary productivity in lentic and lotic habitats. While previous work centered on the macroinvertebrates, this chapter will be confined to using planktonic and periphytic primary productivity and respiration levels to infer nutrient and toxicant concentrations.

The bioassay protocols delineated in the last chapter (4) provide the most precise answers of all the tools in the pollution biologist's arsenal. However, by virtue of the controlled laboratory environment demanded by this approach, it affords the weakest extrapolation to natural communities. The data are limited to narrow generalizations about the studied life stage of the species tested. The formulation of application factors stipulating limiting concentrations for a whole family of toxicants (i.e., anionic detergents, heavy metals, organophosphate pesticides, etc.) on an entire ecosystem demands great courage. Impressive studies have been undertaken, however, to standardize and refine techniques for extending bioassays to whole life cycles and more than one trophic level. Such avenues of development will be of paramount importance to environmental management.

Thus, to evaluate the impact of stress, the pollution biologist draws upon data from several sources: bioassay, toxicity, productivity, and diversity. Each area feeds into the general fund of knowledge. The problems of time and cost investiture, however, remain critical, for the pollution control agency must justify expenditures in terms of derived benefit. The applied biologist, therefore, unlike the researcher, must compromise. He/she must invest his/her effort wisely and budget his/her time to obtain the fullest possible picture of environmental quality. Because of the impetus provided by federal legislation

in the early 1970's mandating the incorporation of an ecological perspective into water surveys, the discipline is enjoying an exponential growth phase. Consequently, the protocols outlined here can only provide a working knowledge into the fundamental approaches of water pollution biology.

The authors would be remiss if we failed to acknowledge the creative contributions of Manuel Correa, Michael Lizotte, Carmen Medeiros, Joel Pratt, Bruce Tease, and David L. Coburn for the cover art.

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August, 1988

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CHAPTER 1

The Data Base

EXERCISE 1/EUTROPHICATION: A REVIEW OF LAKE CHEMISTRY

PURPOSE

THIS introductory exercise is designed to review the basic sequence of lake dynamics that predisposes standing waters to eutrophication as well as to refine your analytical techniques. Accordingly, the chemical milieu characterizing summer stratification and stagnation in a eutrophic lake will be replicated in an illuminated, refrigerated tank (Coler and Romanow, 1975; Visco et al., 1979). While we can produce, in effect, an epilimnion, metalimnion, and hypolimnion, extrapolation to trophogenic and tropholytic zones is not valid, for depth restrictions militate against the attainment of a true compensation level. In this case, photosynthesis is depressed by temperature, rather than by light extinction.

INTRODUCTION

Likens (1972) describes this aging process as the enhanced primary productivity stimulated by organic matter and/or nutrient enrichment resulting in the depreciation of the lake as a recreational resource. Accordingly, we are concerned with those factors that alter the distribution and the consequent biological availability of nitrogen and phosphorous compounds in the trophogenic zone. Probably the most conspicuous chemical factor dictating the form, solubility, circulation, and precipitation of nutrients is the oxidative state of the water column and the underlying sediments of the microzone. For this reason, the class will relate iron, inorganic carbon, nitrogen (NH_3, NO_2^-, and NO_3^-), pH, and phosphorous (ortho and total) levels to

metabolic activity. Since primary productivity is almost exclusively a photosynthetic phenomenon, it will be necessary to trace this process at night as well as during the day.

PROCEDURE

These laboratory periods will be used to identify and demonstrate the physical and chemical factors governing nutrient availability.

Reagent Preparation

Each student will be assigned a parameter group for which he/she will assume responsibility. This will extend to the preparation and maintenance of those reagents requisite for its analysis (APHA, 1985). Also, if indicated, he/she should refresh his/her classmates on the analytical procedure and the basic chemistry of the process. As these reagents will be used in both Exercise 1 and 2, enough of each should be prepared to permit a minimum of 50 analyses.

Sampling

To separate the effects of photosynthesis on the distribution and solubilities of the various chemical constituents from those of respiration, collect samples during both the light and dark portions of the light cycle. During each sampling period, carefully siphon a sufficient quantity of water from each layer (epilimnion, metalimnion, and hypolimnion) to permit duplicate analyses for each parameter being measured. Perform your analyses scrupulously using the procedures detailed in APHA (1985). Record your results [mean ($\bar{x}$) and standard deviation (s), see Exercise 3 for calculations] in Table 1-1. Collect the data for the other parameters from the other groups and compare the results with those found in Wetzel (1983) and APHA (1985).

QUESTIONS

(1) Referring to the data (Table 1-1), trace the sequence of events that account for the observed chemical and physical changes with depth and time. In your answer, pay particular attention to DO, CO_2, NO_3^-, iron, and calcium levels. Wetzel (1983) serves as an excellent reference.

(2) Based on these data, what remedial treatment would you inaugurate to halt or reverse the process?

(3) What would be the advantage of initiating a chemical inventory in the spring?

(4) How many stations and what sampling frequency would be required to survey a stream-fed single basin lake with a single outlet?

TABLE 1-1 Concentrations of indicated parameters in the epilimnion, metalimnion, and hypolimnion of a stratified aquarium during day and night sampling (mean and standard deviation of two measurements).

	Day						Night						
	epi-		meta-		hypo-		epi-		meta-		hypo-		
Parameter	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s	Student
pH													
Acidity													
Alkalinity HCO_3^- CO_3^{2-}													
CO_2													
DO													
% Saturation													
BOD													
Ca													
Hardness													
Fe^{2+}													
P_{ortho}													
P_{total}													
NH_3–N													
NO_2–N													
NO_3–N													
Conductivity													
Suspended Solids													
Turbidity													
Temperature													

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EXERCISE 2/RIVER DIURNAL: A CHEMICAL INVENTORY

PURPOSE

As in the preceding exercise, the intent of this laboratory period is to generate sufficient data to permit comparison of water quality between sampling stations and support speculation regarding their biological carrying capacities. In this instance, we will be generating a data base for a riverine rather than a standing water habitat.

INTRODUCTION

The dominant phenomenon in lake systems is circulation which is responsible for the oxidation and precipitation of nutrients followed by stratification which leads to stagnation, thus causing chemical reduction and their solution. In rivers, except those affected by gross pollution, there is no such sequence. Rather, there is a seasonal pattern of spring erosion followed by deposition. In the river's course to the sea, the process of baseline leveling results in the evolution of mountain riffles and pools to flood plain meanders. The limiting factors, instead of oxygen as in lentic waters, are current and stream bed load. Except for hatched fish, the biota are concentrated in the river bed, whether the food web is grazing or detritus based.

Perhaps of even greater importance is the vulnerability of flowing waters to external inputs. The ratio of shore line to water volume is much greater in streams than in lakes. Given the fact that most pollutants adsorb to suspended

particles and slowly leach out upon settling, river chemistry should include analysis of the interstitial and boundary layer waters where the biotic community is concentrated.

Subsequent laboratory exercises will be biologically oriented, focusing on the application of various indices to resolve subtle differences in water quality between the control and test stations studied in this exercise. Remember, it is the aquatic biota that integrate the total environment, thus providing a yardstick for assessing water quality. The biota provide a summation of the water conditions over time, whereas corresponding chemical and physical tests must be performed over a longer period to provide average values. Also, according to Tarzwell (1957), biological surveys and investigations are valuable tools for determining the effectiveness of natural purification processes of streams and their assimilation of and accommodation to changes in the environment by effluent discharges and allochthonous materials.

As analytical values in streams may differ with flow, depth, and distance from the shore, it is best, if the equipment is available, to take an integrated sample, composited by flow, from top to bottom in midstream (Hem, 1970; APHA, 1985). Since the mean velocity of the stream is at a depth approximately 0.6 of the distance from the surface to the bed, it has been suggested that samples be collected from this depth (Klein, 1959), although middepth is often recommended (Kittrel, 1969; APHA, 1985).

PROCEDURE

Since we are occupied here with environmental suitability, our concern is with extremes. Consequently, it is important to monitor the water quality over a 24-hour period to identify batch release regimes often employed by some industries.

For your assigned parameters, use the reagents prepared in Exercise 1 to conduct a preliminary analysis of the stream water to determine concentration ranges. Also, if the study site has a problem with a particular pollutant not listed in Table 2-1, reagents should be prepared and its concentration measured. Prepare to perform duplicate analyses for samples from both stations at four-hour intervals. For our purposes, a single grab sample, of sufficient volume to allow all of the necessary determinations to be made, collected from the middle of the stream at middepth will be adequate for each station for each sampling period. Collect, store, and analyze the samples as described in APHA (1985).

The flow rate should be measured at both sites at the beginning and end of the survey. To do this, determine the cross-sectional area of the stream at both sites. Then, using a current meter, determine the average stream velocity at

TABLE 2-1 Concentrations of indicated parameters at stations one and two at four-hour intervals (mean of two measurements).

	Sampling Period												
	Station		Station		Station		Station		Station		Station		
Parameter	1	2	1	2	1	2	1	2	1	2	1	2	Student
pH													
Acidity													
$Alkalinity_{total}$													
CO_2													
DO													
% Saturation													
BOD													
Ca													
Hardness													
P_{ortho}													
P_{total}													
NH_3-N													
NO_2-N													
NO_3-N													
Conductivity													
Suspended Solids													
Turbidity													
Temperature													
Flow													
Others													

each site. The flow (m^3 or ft^3/second) is equal to the cross-sectional area multiplied by the average stream velocity.

Record the data in Table 2-1. Plot the parameter concentrations versus time for both stations, using a single graph for each group of parameters.

QUESTIONS

(1) Compare the trends evident here with diurnal changes observed in lakes.

(2) How would you correlate changes in water quality in time and distance with land use and human activity? Prepare a land use map from a USGS topographic map to explain mass balance.

(3) To what extent is primary productivity autochthonous? Support your answer with field data.

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CHAPTER 2

Structural Aspects of Biotic Communities--Benthic Macroinvertebrates and Periphyton

PURPOSE

POLLUTION biologists are severely limited by time and cost constraints in their attempt to obtain and process statistically representative samples. Both the taxonomy and contagious distribution of the organisms preclude a rapid assessment of the biotic response. Meaningful chemical data, on the other hand, can be generated on site in a fraction of the time from far fewer samples. Hence, the biological component of a survey is often quantitatively weak—though it is the most critical.

This chapter intends to acquaint you with some of the measures implemented by field biologists, to familiarize you with the major taxa, and to demonstrate their application as indicators of water quality.

INTRODUCTION

The Water Quality Act of 1965 (PL 89-234), an amendment of the Federal Water Pollution Control Act of 1956 (PL 84-660), required each state to establish standards for all interstate waters, including coastal waters, and to develop a plan of implementation and enforcement of these limits. A more recent amendment, the Clean Water Act of 1977 (PL 95-217), established a national goal to prohibit the discharge of toxic substances in toxic amounts. Both pieces of legislation stress the importance of the biota in establishing water quality criteria.

Much emphasis is currently being placed on chemical and physical tests because these parameters, which provide such data as temperature, dissolved oxygen, pH, salinity, hardness, turbidity, etc., are easily defined and produce an estimate of the present water quality. However, such data provide no biological perspective into chronic synergistic effects of subclinical stress.