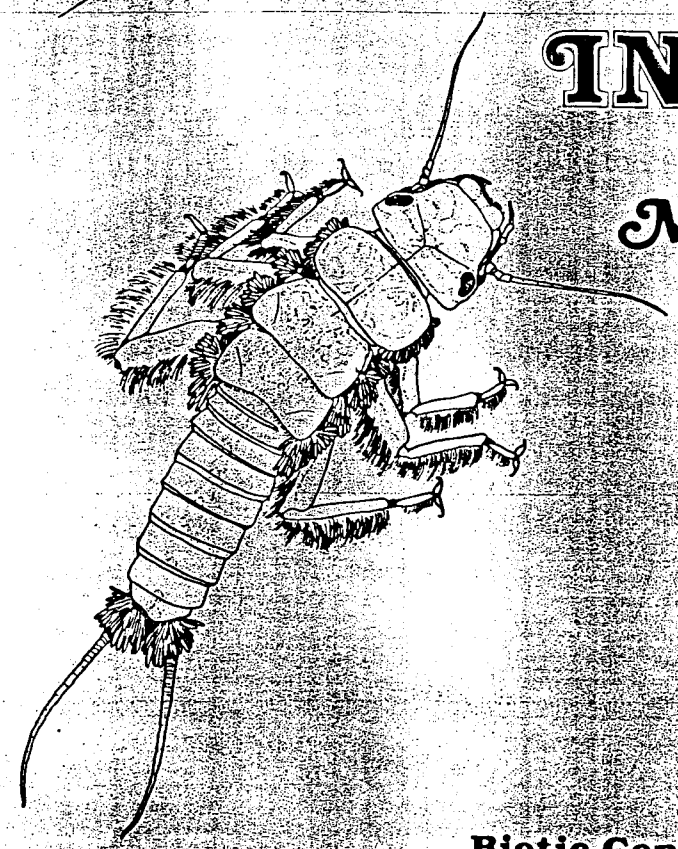
SD
Biotic Condition Index...
In DB
#75926

AQUATIC ECOSYSTEM INVENTORY



Macroinvertebrate Analysis

Biotic Condition Index: Integrated Biological, Physical, and Chemical Stream Parameters for Management

Library - Ogden Center
Rocky Mountain Research Station
324 25th Street
Ogden, UT 84401

RECEIVED
APR 28 2003
BY SB/RPS

U.S. Forest Service
Intermountain Region
October 1979

3624

FOREWORD

The Intermountain Region has developed the General Aquatic Wildlife System (GAWS) as a wildlife management information system. The system provides guidelines for the elements of stream analysis, lake-reservoir-pothole analysis, macroinvertebrate analysis, data management, stratification criteria and surface waters catalog of numbers.

Macroinvertebrate analysis is the least understood and the most preplexing element of GAWS, although it is an important tool in describing the biotic potential and relative health and productiveness of aquatic ecosystem functioning. By development of a scorecard index, scientists will be better able to describe the condition and trend of aquatic systems.

This publication contains a paper that describes a macroinvertebrate analysis program for stream ecosystems. This work was performed under contract to Robert N. Winget, PhD., BYU, Provo, Utah. In phase I of the study the work involved a synthesis of ideas which resulted in the paper "A Systematic Approach to Management by Objective for USFS Stream Fisheries." The phase II study completed the total effort and resulted in the paper "Biotic Condition Index: Integrated Biological, Physical and Chemical Stream Parameters for Management" reprinted here in its entirety.

BIOTIC CONDITION INDEX: INTEGRATED BIOLOGICAL, PHYSICAL, AND CHEMICAL STREAM PARAMETERS FOR MANAGEMENT

Robert N. Winget, Ph.D.
Director, Aquatic Ecology Laboratory
Department of Zoology
Brigham Young University
Provo, Utah 84602

and

Fred A. Mangum, Ph.D.
Aquatic Ecologist
Uinta National Forest
Provo, Utah 84602

October 17, 1979

Prepared under Contract No. 40-84M8-8-524
U.S. Department of Agriculture
Intermountain Region, Forest Service
Donald K. Dunham, Regional Aquatic Ecologist
Contracting Officer Representative

TABLE OF CONTENTS

	Page
PERSONNEL	i
ABSTRACT	iii
INTRODUCTION	1
RATIONALE	2
Systems Modeling	2
Habitat, Water Quality, and Biotic Relationships	2
Indices of Diversity, Condition, etc.	3
STUDY PLAN	7
METHODS, RESULTS, AND DISCUSSION	8
Correlation of Physical/Chemical Determinants with Number of Taxa	8
Macroinvertebrate Tolerance Quotients (TQ)	10
Community Tolerance Quotients (CTQ) and Biotic Condition Index (BCI)	10
APPLICATION AND VERIFICATION	11
Management Priorities	11
Determining Biotic Condition and Trend	12
STREAM RATING USING THE BIOTIC CONDITION INDEX (BCI)	14
CONCLUSIONS	15
FIGURES	16
TABLES	25
REFERENCES CITED	46

PERSONNEL

Robert N. Winget, Ph.D.	Principal Investigator, Author
Fred A. Mangum, Ph.D.	Co-principal Investigator, Advisor
C. Selby Herrin, Ph.D.	Data Processor, Consultant
Donald K. Dunham	Contracting Officer Representative, Intermountain Region, Forest Service
James A. Drake	Graduate Assistant
Julia Farr	Secretary
Corrine Hamilton	Typist

ABSTRACT

BIOTIC CONDITION INDEX: INTEGRATED BIOLOGICAL, PHYSICAL, AND CHEMICAL STREAM MANAGEMENT. Robert N. Winget, Ph.D.[1], Fred A. Mangum, Ph.D.[2].

Many different biotic indices have been formulated to describe effects of environmental changes on biotic communities. Factors such as numbers of species, numbers of individuals, evenness, trophic habits, environmental tolerances, and niche width have all been used in various combinations. None of them have proven really effective as stream management tools.

The Biotic Condition Index (BCI) developed during this study incorporates stream habitat, water quality, and environmental tolerances of aquatic macroinvertebrate community species. It is a function of a Predicted Community Tolerance Quotient (CTQp) divided by the Actual Community Tolerance Quotient (CTQa). The BCI is sensitive to different types of environmental stress; it gives a linear assessment from unstressed through all levels of stress; it is applicable to many types of streams; and it evaluates a stream's condition in relation to its own potential, not that of a theoretical stream. The BCI provides the basic data for setting realistic management priorities and existing stream habitat and/or water quality management programs—providing a needed reliable biotic component.

[1]Aquatic Ecology Laboratory, Department of Zoology, 115 Page School, Brigham Young University, Provo, Utah 84602.

[2]Aquatic Ecology Laboratory, Uinta National Forest, Provo, Utah 84601.

INTRODUCTION

In the Intermountain Region, the U.S. Forest Service is in the process of developing a stream water quality/habitat management program. In this program they are attempting to integrate various habitat components (water column, substrate, bank vegetation, bank stability, and channel stability), and a biological component (aquatic macroinvertebrates) into a stream management model (GAWS). This study forms the biological component of that model and was made possible in part through a Forest Service contract number 40-84M8-8-524. Utah Power and Light Company has also been instrumental in providing support (1970-1979) to the Aquatic Ecology Lab, Brigham Young University, enabling the development of methodologies used in this study. Data used in the analyses have been obtained from the files of the Forest Service Aquatic Ecology Lab, Uinta National Forest, and Aquatic Ecology Lab, Brigham Young University, both at Provo, Utah.

Glass, Peckham, and Sanders (1972) reported "the assumptions of most mathematical models are always false to a greater or lesser extent. The relevant question is not whether...assumptions are not exactly, but rather whether the plausible violations of the assumptions have serious consequences on the validity of probability statements." Green (1979) stated that in selecting a method of analysis in modeling, the first consideration should be which method is most efficient in providing the desired product. "If the most efficient possible method appropriate to the hypothesis model turns out to be one based on ranks, then so be it." Mosteller and Rourke (1973) emphasize you should not be locked into cookbook approaches but it is often best to design your own test.

Indeed, relationships do exist between biotic communities and physical/chemical conditions. Most models are based upon lines of best fit—straight lines or regular expotential curves, but biotic stream communities rarely follow regular sequencing in degrees of variance whether comparing one community's change over time or variances between communities per time. As stated by Green (1979): "Many environmental biologists throw species abundance data into computer ordination programs, most commonly factor analysis, forgetting that in their first ecology course they learned that species have optima on environmental gradients—unimodal distributions rather than linear ones. Misleading results are obtained when a linear model ordination is carried out using such data (Swan 1970, Noy-Meir and Austin 1970, Austin and Noy-Meir 1971, LaFrance 1972). When they are applied to species distributed along one environmental gradient, usually a curve in a two-dimensional ordination space results. This has been called the horseshoe effect (Kendall 1975, Fasham 1977)."

One thing is certain—any attempt to model an ecological system(s) must be geared to a specific purpose and only those components specifically related to that purpose should be used. With this in mind the authors designed a simplified stream quality evaluation model for western mountain and valley streams. The objective of developing this predictive model was to provide a reliable biological component to be used in conjunction with various stream fisheries habitat studies such as: the USFS GAWS program (Intermountain Region); USBLM Fisheries and Aquatic Habitat Management (Duff, 1975); and the in-stream flow studies, USFWS.

RATIONALE

Systems Modeling

There have been numerous attempts at developing ecological models to describe the complex interactions of ecosystems as well as predict community responses to environmental changes. Green (1979) in reviewing a paper by Levins (1966) stated that "in environmental studies a model that completely described the complex systems involved would have to have hundreds of simultaneous partial differential equations with time lags and hundreds of parameters. Simplification is both legitimate and necessary...one must choose among three possible strategies in model-building. The perfect model would have the attributes of generality, realism, and precision. In practice one of these must be sacrificed, and which it is defines the strategy." Skellam (1969) reported that no models are perfect but "what really matters is not their degree of perfection, but their adequacy for prescribed purposes." He further emphasizes that environmental biologists often collect massive sets of data and subject them to any available computer package multiple regression program with no clear hypothesis model in mind.

A model which must account for all input-output behavior of a real environmental system and be valid for all circumstances is impossible to develop (Ziegler, 1976). Halfon (1979) contends that any ecological model must be based upon knowledge of the real system obtained through research experience. Watson and Loucks (1979) have come to the conclusion that to grasp the functioning of a system, its tremendous complexity must be reduced to a minimum set of structural components which are believed to be distinct in affecting the functioning of that aspect of the system which is of interest.

Habitat, Water Quality, and Biotic Relationships

There are numerous references illustrating the effects of stream components such as substrates, riparian vegetation, riffle/pool ratios, pool quality, bank cover, flow regimes, elevation, gradient, and water quality on macroinvertebrate communities. Use of biotic communities to assess water quality, specifically macroinvertebrate communities, is not a new concept (Cairns, 1970, 1973, 1977; Cairns, Lanza, Sparks, and Waller, 1973; Ghetti and Bonazzi, 1977; Hunt, 1976; Moyle, 1976; Olive, 1976; Reichert, 1973; Resh and Unzicker, 1975; Thomas, 1976; Truett, 1975; Wilhm and Dorris, 1968). Macroinvertebrate communities are directly related to their physical/chemical environs (AFS, 1967; Armitage, 1958; Barber and Kevern, 1973; Bell, 1969; Cairns, Dickson, and Herricks, 1977; Chutter, 1969; Cummins, 1973; DeMarch, 1976; Egglishaw, 1968; Erman, Newbold, and Roby, 1977; Harrel and Dorris, 1967; Hart and Brusven, 1976; Luedtke, Brusven, and Watts, 1976; Pennak, 1977; Resh and Unzicker, 1975; Stoneburner, 1977; Ulfstrand, 1967; Ward, 1975; Werner, 1977; Williams and Hynes, 1976, 1977; Williams and Winget, 1979; Winget 1976a, 1976b, 1977a, 1977b, 1977c).

A recent reference work that should prove helpful to aquatic ecologists is "An Introduction to the Aquatic Insects of North America" edited by R. W. Merritt and K. W. Cummins (1978). Most genera of aquatic macroinvertebrates in North America are classified as to habitat, habit, trophic relationships, North American distribution, and a list of ecological references is given for each.

It is important to realize that what is natural for one stream is not necessarily natural for another stream. Comparing two unperturbed streams, biotic production of one may be two or more times greater than the other. The same is true for species richness. This is usually the result of differences

in water quality (Altman and Dittmer, 1966; Cairns, Dickson, and Herricks, 1977; Hart and Fuller, 1974; Hynes 1971, 1972; Macan, 1974), water temperature (Altman and Dittmer, 1966; AFS, 1976; Hooper, 1973; Hynes, 1972; Jones, 1972; Macan, 1974; Williams and Winget, 1979), upstream land and/or water use (Bakke, 1977; Cairns et al., 1977; Hynes, 1971; Platts, 1979; Ringler and Hall, 1975) stream gradient and/or elevation (Baumann, Gaufin, and Surdick, 1977; Hynes, 1972; Macan, 1974; Reice, 1977; Stoneburner, 1977; Stout and Vandermeer, 1975; Wiggins, 1977) or a combination of these and other factors. Aquatic macroinvertebrate taxa respond differently to environmental conditions, each one being found within definite ranges of conditions. This environmental limitation to distribution or occurrence has been called niche width or breadth (Colwell and Futuyma, 1971; Pielou, 1972).

If a stream management program is to be successful it will have to take into account the: (1) Physical Habitat Component; (2) Water Quality/Hydrology Component; and (3) Biological Component.

Indices of Diversity, Condition, etc.

In trying to describe the effects of different environmental conditions on biotic communities, many different biotic indices have been formulated. The dominance diversity indices are probably the most widely used in impact assessment investigations (Cairns and Dickson, 1971; Cairns, Dickson, and Lanza, 1973). For a discussion of the theories behind the uses of dominance diversity indices the reader is referred to Margalef (1958), Brillouin (1960), Shannon and Weaver (1963), Lloyd and Ghelardi (1964), Pielou (1966a, 1966b, 1966c), Wilhm (1967, 1970a, 1970b), Wilhm and Dorris (1968), Chandler (1970), and Nuttell and Purves (1974).

The dominance diversity indices are based upon the contention that maximum diversity, and thus maximum information, exists in a community of organisms when each individual belongs to a different species. Minimum diversity exists when all individuals belong to the same species. A community in which all individuals belong to the same species is high in redundancy and low in information. Wilhm and Dorris (1968) pointed out that an unfavorable limiting factor, such as pollution, results in detectable changes in community structure, and as it relates to information theory, more information or diversity is contained in a natural community than in a polluted community. The polluted system is supposedly simplified and those species that survive encounter less competition and therefore are usually able to increase in numbers. Redundancy in this case is high since the probability that an individual belongs to a species previously recognized is increased and the amount of information per individual is reduced.

The contention that a simplified system is a polluted system is erroneous. The high mountain headwater streams of the Uinta Mountains in Utah contain simplified communities, but the simplification of the system in these rivers comes from water quality approaching that of distilled water which is unsuitable for many aquatic organisms because of its lack of desirable substances (Winget 1976). Many desert streams in Utah have natural shifting sandy substrates, extreme fluctuations in ambient temperatures and stream discharges, which result in simplified communities, but not as a result of pollution (Winget 1977). These conditions have existed for thousands of years and the organisms found in these streams are well adapted for this type of situation and definitely belong to natural communities; but, community diversity is low.

The dominance diversity indices were primarily set up to evaluate conditions such as heavy organic enrichment from industry, municipal wastes, or even agricultural processes, and they do reflect such impacts as reduction of total species with drastic increases in the number of organic pollution-

tolerant forms. But in systems subjected to moderate levels of pollutants such as toxic wastes, temperature fluctuations, shifting substrates, fluctuating stream discharges, periods of siltation or scouring, the dominance diversity indices are often poor indicators of the variants of these communities from natural conditions.

An example of dominance diversity indices not reflecting effects from some types of pollution is given by Masnick, Stauffer, Hocutt, and Wilson (1976). In studying an oil spill in Plum Creek, eight stations, 2 above and 6 below the spill, were sampled for macroinvertebrates and fishes. Both fish and macroinvertebrate data were analyzed using a dominance diversity index. Diversity index values calculated from both fish and macroinvertebrate data from stations 3 to 7 showed great variability when compared to the control stations. There seemed to be no relationship between the proximity of the oil spill or the straw dams erected to capture the oil and the diversity of the organisms. Hoehn, Staufer, Masnik, and Hocutt (1974) reported further on the effects of the oil spill in Plum Creek. They said that based on the available data, the effect of the oil spill was a toxic one rather than one of rendering sediments unsuitable for colonization. They based this conclusion on the fact that the diversity did not change even though the total numbers of organisms decreased, indicating that each taxa within the community was effected equally rather than selectively. Therefore, the effects of this particular oil spill was non-selective. They also said that the low number of organisms recovered at the first control station was attributed to contamination of that site by drainage from a cow pasture. This would indicate that perhaps other environmental factors were more influential on the diversity indices than was the oil spill.

Hendricks, et al. (1974) reported on the utilization of diversity indices in evaluating the effects of paper mill effluents on bottom fauna. It was interesting to note that the diversity indices at four sites sampled showed no correlation with the point of discharge from the paper mill. They concluded that natural conditions of the river had already lowered the diversity value of benthic communities in the river, and that the effect of the paper mill was hidden by these natural effects. It was evident from the data in their paper that the dominance index they used (Shannon-Weaver) was not adequate in defining the actual impacts of the paper mill on the aquatic macroinvertebrates.

Mackay, Soulsby, and Poodle (1973) concluded: from the review of Shannon-Weaver index ($\bar{d}$) values from 50 unpolluted streams with a wide range of chemical, geological, and physical characteristics; that $\bar{d}$ values are open to individual interpretation as to what levels are indicative of pollution.

Mathis (1968) compared species diversity of benthic macroinvertebrate communities in three mountain streams with those of a non-polluted and two polluted lowland streams. He came to the conclusion that high mountain streams and lowland moderately polluted streams have maximum diversity. He theorized that moderate loads of oil field brines do not have the effect of lowering species diversity, but probably cause the replacement of fragile species with more tolerant ones accompanied with an equalizing of the distribution of numbers over the species present, thus higher dominance diversity values.

Susan Cook (1976) reported that mild amounts of some substance may be associated with an increase in the value of $\bar{d}$. In contrast, large amounts of organic enrichment lower the index by favoring only certain species. Thus, it would appear that the Shannon-Weaver index may be useful only for indicating relatively large inputs of pollutants, and thus not reliable for continuous assessment of water quality.

Harrell and Dorris (1968) found that in an intermittent stream in Oklahoma which received an influx of oil field brines, Station 9 (4) which received moderate amounts of the brines showed an increase of number of species, number of individuals per meter squared, and a significant increase in the Shannon-Weaver index (d). In fact, in the unpolluted section of stream, the index was 1.78 and in the area of moderate pollution it was 3.15. At another station further downstream, Station 22 (5), there was a heavier load of brines and the number of taxa still remained high, but this seemed to allow a large dominance by a few species, thus the Shannon-Weaver index showed quite a decline to only 1.58 at this site. Further downstream, approximately 4 kilometers below the point of influx, the number of species had increased and the number of individuals per meter squared had dropped off drastically with an increase in the Shannon-Weaver index to 3.84.

Zand (1976) concluded that the usage of a diversity index as a sole indicator of the status of an ecosystem needs more rigorous evaluation. Also, he said that initial naming of the information content of a message as the diversity index in biological collections might have been an oversimplification of a very complicated and intuitive diversity phenomenon. Other terms, such as information content of the collection, might have been more proper. He proceeds to say that the total number of species in the collection, another important variable, just might yield indices that could be termed the diversity index more appropriately than those indices which report the value of relative evenness.

It is apparent that dominance diversity values are open to criticism, and interpretation of these values calls for extreme caution. It is imperative that any interpretation be accompanied with substantial supportive data such as number of taxa (DeJong, 1975), density, standing crop, rather complete species list (Resh and Unzicker, 1975), and physical and chemical description of the system (Mackay et al., 1973; and Mathis, 1968).

To many, it is surprising to note the sharp increase in dominance diversity from pristine conditions to moderately stressed or polluted situations. But, pollutants added in small concentrations to "clean water" systems often result in an increase in community diversity. Following are three possible reasons why moderate pollution increases dominance diversity index values: (1) When the perturbation being added eliminates one or more of the very fragile species it allows these to be replaced by other more hardy species, and these more hardy species may be able to account for a higher percentage of the total numbers than the replaced fragile forms, thus evening the spread of the total population over a larger number of species, and thus an increase in community dominance diversity. (2) When the perturbation is non-selective it has a greater impact on the dominant forms simply because there are more of them exposed, causing a reduction in their numbers. This in itself would even out the distribution of numbers over the total species and thus result in an increase in the community diversity. (3) The addition of a substance may provide a previously limited chemical, allowing additional species to become established, and thus increasing community diversity.

As perturbations become severe enough to actually cause a reduction of species, an increase in the competitive potential for some remaining species often results, allowing their numbers to become much greater compared to other remaining species, and the community diversity decreases.

In high mountain streams, waters are often devoid of dissolved substances essential to healthy diverse macroinvertebrate communities. Additions of nutrients and salts to these streams would actually benefit the communities. As these rivers proceed down through the drainage, salts and nutrients are added naturally and there is an increase in the condition of the communities—more

species are present and there are higher total numbers with a more even distribution of numbers over available species, and thus community diversity increases. Proceeding down into the valley the dissolved solids, salts, and nutrients increase to a nuisance level, resulting in a decrease in numbers of species and increased dominance of the more environmentally tolerant species—thus reduced community diversity.

Harrel and Dorris (1968) reported annual numbers of species and total community species diversity (Patten, 1962) increased in 3rd, 4th, and 5th order streams and decreased in the 6th order stream. They also noted that proceeding downstream, total diversity and redundancy values for Otter Creek, a natural stream, showed the same general pattern as reported for streams that receive pollutional effluents. Harrel and Dorris (1968) emphasized the pattern of diversity in Otter Creek was due to physiographic stream succession, rather than the influence of effluents. Wilhm (1965) and Mathis (1965) also reported similar findings.

It appears that in order to have an index that is really sensitive to changes in water quality, an index will have to be developed that has a weighted value for the various taxa in the communities, and this weight will have to not only be based on their occurrence—presence or absence—but also upon the relative tolerance of each to changing environmental conditions.

Cook (1976) stated the following conditions for the ideal pollution index: (1) the index should be sensitive to the stressful effects of pollution on the aquatic community; (2) it should be of general application to various types of streams; (3) it should give a continuous linear assessment from unpolluted conditions; (4) it should be independent of sample size; and (5) it should be simple for gathering the data and for calculation.

Several workers, realizing the importance of individual species in determining community diversity and condition have proposed various indices. These are based upon the tolerance-intolerance of species to environmental perturbations. Beck (1954, 1955) developd such an index, based largely upon the early work of Kolkwitz and Marsson (1908, 1909).

Chandler (1970) developed a system, called the Chandler Score, for use in a stream in Scotland. In the Chandler score system, the taxa were rated starting at the top with the very fragile species and progressing down to the heavily tolerant species. Those at the top, the intolerant species, were given high values nearing 100 and those highly tolerant species were given low values near 0. A taxon with a value of 90 was given a value of 95 if it was very abundant, or a value of only 85 if it was rare. In this way there was an abundance value entered as well as its tolerance to pollution. In the Chandler score system, the numerical value for all taxa were added up, but this gave a very wide range of scores, anywhere from less than 100 to up to several thousand. This method is susceptible to great variance according to the type of investigator. If the investigator is a taxonomic "lumper" the score would be low or if a "splitter", the score would be high.

Cook (1976) proposed a modification of the Chandler Score. In her modification she assigned taxa encountered a value in the same type matrix that Chandler used. This is one area that error might creep in if the investigator is not knowledgeable in assigning various taxa their respective environmental ratings. Next, she summed the total score and divided it by the number of taxa used in her evaluation. All evaluations, no matter what stream or the number of taxa, had a value between 0 and 100. She claims that the modified Chandler Score should be fairly sensitive to moderate changes in water quality. Thus, instead of having the increase in the index values with moderate levels of

pollution, as with dominance diversity indices, this index would show a linear response through the whole scale of water quality conditions, decreasing with each increase in perturbation. This would fulfill one criteria of a desirable water quality index not fulfilled by the dominance diversity indices such as the Shannon-Weaver, the Brillouin, or the Sequential Comparison index.

The modified Chandler Score is based upon subjective tolerance ratings for macroinvertebrate taxa encountered. Such ratings are subject to investigator biases related to past experience. The ideal index would follow the rationale of Cook (1976) but would have tolerance values mathematically derived and based upon individual taxon's responses to natural environmental variants rather than man-caused changes. It would also have the ability to compare actual condition with an expected natural condition rather than an "ideal" desired, although often impossible condition. A low-valley stream will never be a high mountain stream and each, even under "natural" conditions will have different biotic communities.

STUDY PLAN

As discussed under Rationale, aquatic insect stream communities respond to their physical/chemical environs. If the community response(s) to several of the more important determinants (physical/chemical stream characteristics) can be defined, then a measurement of these determinants for a given stream should provide the basis for predicting an expected or potential community for that stream. Once a reliable predictive base is provided, comparison of an actual community with a predicted should provide the basis for stating the actual community condition in terms of a realistic expected value.

Based on the above assumptions, a stream aquatic macroinvertebrate community model was formed following these steps:

1. Raw data (biological and physical/chemical) from 164 station dates were regressed to determine significant relationships.

2. Total alkalinity, sulfate, stream gradient, and substrate composition were selected due to their strong influence on the aquatic macroinvertebrate communities, their ease of measurement, their availability in the literature and field records, and their relative independence of unnatural stream perturbations.

3. Physical/chemical values were transformed to better fit them linearly to biological species richness (number of taxa). This was done so the relative importance of levels of the 4 selected determinants of community structure could be determined.

4. Based upon their individual response to the 4 selected determinants, 54 taxa were assigned tolerance quotients indicating their environmental hardiness. A cluster analysis of their associations confirmed the accuracy of assigned values. Using species associations as the basis, a total of 371 taxa were assigned tolerance quotients.

5. From the above analyses, a predictive model was prepared from which a predicted community tolerance quotient (CTQp) can be extracted, given values for the 4 determinants. This is an expression of what the biotic condition should be under the environmental conditions defined by the determinant values.

6. The actual taxa tolerance quotients for a stream section were averaged giving an actual community tolerance quotient (CTQa). The predicted community tolerance quotients (CTQp) were divided by the actual community tolerance quotients (CTQa), then multiplied by 100 giving percent biotic condition index (BCI) values.

7. The CTQa and BCI, coupled with stream habitat values, form the basis for setting stream management priorities.

METHODS, RESULTS, AND DISCUSSION

Correlation of Physical/Chemical Determinants with Number of Taxa

A total of 164 sets of macroinvertebrate samples from over 20 different streams were analyzed for correlation between number of taxa and various physical/chemical stream characteristics. The following results were obtained:

RELATIONSHIP	CORRELATION COEFFICIENT (r)
Density & Total Alkalinity	+0.478*
Biomass & Total Alkalinity	+0.673*
Taxa & Total Alkalinity	−0.668*
Taxa & Sulfate	−0.420*
Taxa & % Gradient (transformed)	+0.520*
Taxa & Substrate Dominance Index	+0.563*
Taxa & Boulder Dominance	+0.402*
Taxa & Rubble Dominance	+0.414*
Taxa & Gravel Dominance	-0.165^{NS}
Taxa & Sand/Silt Dominance	−0.590*
Taxa & Transformed Site Index	+0.701*

*Significant at the 0.001 level with N = 100 Actual N = 164

Results of linear regression tests between number of macroinvertebrate taxa and the same physical/chemical stream traits used in the correlation tests, are given in Figures 1, 2, 3, 4, and 5 including the regression equations and the transformed values used for stream gradient and substrate composition. Figure 5 shows the strong positive linear relationship between actual number of taxa and the assigned habitat quality values (transformed site index).

A correlation coefficient (r) of +0.701 between assigned habitat values and number of taxa indicates approximately 49 percent ($r^2 = 0.49$) of the variance in number of taxa is accounted for by the selected variants. This is excellent for our model since we are concerned only in natural community determinants—e.g., those environmental factors that are not strongly related to man-caused perturbations but still affect biotic community composition. Other factors related more closely to land and water use also exert strong influences on macroinvertebrate communities—e.g., stream minimum flows, toxicant pollution or organic enrichment, increased water temperatures, etc. Changes caused by these factors are important in our model, but their influence appear as community variance from the predicted "natural." This approach allows comparison of an actual condition against a realistic potential for that system rather than a standard which may be unobtainable for many systems.

In our model 4 stream, characters were selected as independent variables because of strong relationships between them and community dependent variables-diversity, density, and/or biomass. Total alkalinity was selected because it correlates so closely with community density (Figure 6) and standing crop or biomass (Figure 7). Alkalinity is important in the primary production of a stream, especially in the absence, or near absence, of free carbon dioxide. Many species of algae can utilize bicarbonate ions as a CO_2 source of photosynthesis. Alkalinity also often increases in concentration as a stream picks up other elements essential in the metabolism of plants, invertebrates, and vertebrates. It is not surprising then that alkalinity correlates positively with density (Figure 6), standing crop (Figure 7), and diversity (Figure 1) of a community.

Sulfate was selected because an increase in concentration is generally indicative of natural water quality deterioration and macroinvertebrate community diversity correlates negatively with sulfate concentrations (Figure 2). Many geological formations common in the west such as the Carmel, Chinle, Shinarump, and Mancos Shale contribute fine sediments, total dissolved solids, salinity, hardness, and sulfates to any waters intersecting them. Most poor quality waters of the western U.S. have high sulfate levels. Agricultural irrigation return flows have high sulfate levels, alkaline and saline ground waters have high sulfates and most streams increase in sulfates as they proceed downstream from their sources out into the valleys.

Many workers (Bell, 1969; Brusven and Prather, 1974; Chutter, 1969; Cummins, 1966 and 1974; Hynes, 1972; Luedtke, Brusven, and Watts, 1976; Merritt and Cummins, 1978; Ward, 1975; Williams, 1978) have reported a strong relationship between macroinvertebrate community structure and stream substrates. Rubble and gravel are reportedly the preferred substrates for the greatest number of species. In our surveys this was also the observed case (Figure 4)—boulder and rubble preferred, sand or silt avoided, gravel alone showed no correlation but mixed with rubble or boulder was highly selected for. The larger substrate materials provide a greater diversity of microhabitat than smaller substrates. This allows greater opportunity for community diversity in larger substrates than in fine sands or silts.

Stream gradient was also selected because of its positive correlation with macroinvertebrate community diversity (Figure 3), and its relationship to a stream's ability to maintain substrate quality. A stream's natural substrate composition is a function of the types of associated stratum, total stream discharge and channel gradient. The stratum determines the possible substrate materials available to the stream. The total discharge, especially seasonal high and low flows plus channel gradient determines the stream's ability or tendency to erode or deposit sediment. An eroding stream (high water velocities) will generally have more clean rubble and gravel substrates while a depositing stream (slow water velocities) will have more sands and silts. The gradient is important in this process because water velocity increases with gradient even if total discharge remains constant. With increasing gradient, a stream's ability to maintain clean rocky substrates also increases. Water temperature and dissolved oxygen are also related to gradient. Recovery from perturbations such as thermal pollution or oxygen depletion is quicker in turbulent streams (those with higher gradients and coarser substrates) than slow flowing low gradient streams.

The four independent variables in this model include a density/biomass component (total alkalinity), a water quality component (sulfate), a diversity of microhabitat component (substrate), and a stream maintenance and recovery component (gradient).

Macroinvertebrate Tolerance Quotients (TQ)

The tolerance quotient is the product of 4 component values (Figure 8) derived from the taxon's tolerance to levels of alkalinity and sulfate plus its selectivity for or against fine substrate materials and low stream gradients. Figure 8 gives the values assigned each taxon over a range of values or composition. All are self explanatory except the substrate component. Substrate materials of a given stream station are listed in order of dominance 1-4. If sand or silt is either 1 or 2 in dominance the component value is 4 but if rubble and gravel were the two most dominant the value would be 3 and if rubble and boulder were dominant 2 would be the value.

If a taxon, say *Ephemerella grandis* (Table 1), shows a tolerance to alkalinities >200 but <300 mg/*l* (value of 2), sulfates less than 150 mg/*l* (value of 1), gradients to less than 1.0% (value of 3), and tolerates considerable sand (value of 4), then its tolerance quotient (TQ) would be 2x1x3x4 = 24. Tables 2, 3, and 4 show the justification for assigned TQ's for *Ephemerella doddsi, Cheumatopsyche* spp. and *Brachycentrus* spp., respectively. Tolerance quotients range from 2 to 108. The more tolerant a particular taxa is to environmental stress, as determined by the determinants of our model, the higher the tolerance quotient.

This TQ analysis was completed for 54 taxa. Figure 9, a cluster dendogram based upon the Jaccard Similarity Index, depicts the frequency of co-occurrence of any of these 54 taxa. The TQ's were added after the clustering. The strong clustering of taxa with similar tolerance quotients is highly significant. This illustrates the credibility of the determinants selected, the weighted values given each and the TQ's assigned these 54 taxa.

Using community associations and experience gained from sampling aquatic macroinvertebrates from over 200 streams, 371 taxa to date have been assigned tolerance quotients (Table 5).

Community Tolerance Quotients (CTQ) and Biotic Condition Index (BCI)

The predicted Community Tolerance Quotient (CTQp) is the mean of the tolerance quotients (TQ) for a predicted macroinvertebrate community. The predicted macroinvertebrate community resulted from niche width analyses of the macroinvertebrate data from over 700 samples from 65 stations on 20 different streams. Linear regression, correlation coefficient analyses, similarity index matrices and Jaccard similarity coefficient clustering analyses were used to select representative taxa likely to occur together under various combinations of habitat descriptors (stream gradient, stream substrate composition, total alkalinity, and water sulfate concentrations). Tolerance quotients (Table 5) for the predicted taxa were summed and divided by the number of community representatives giving an arithmetic mean tolerance quotient for that community (CTQp).

To obtain a CTQp for a particular stream segment, first classify the station according to the criteria in Table 6: first, stream gradient; second, stream substrate; third, total alkalinity; and fourth, sulfate. For example, a stream with a gradient of 1.5%, gravel/rubble the dominant substrate, alkalinity ranging from 80-130 mg/*l* and sulfate levels ranging from 7-35 mg/*l* would have a CTQp = 50 (Table 6).

Actual Community Tolerance Quotients (CTQa) are simply arithmetic means of the tolerance quotients (TQ's) of sampled macroinvertebrates from any given station on any given date.

In order to evaluate the actual macroinvertebrate community condition against a predicted potential or expected condition simply divide the CTQp by the CTQa and multiply by 100. The result is a biotic condition index (BCI) which usually ranges from 45 to 100 and is actually an index of percent of predicted. The actual CTQa is usually greater than the predicted CTQp due to impacts from factors not considered in our model. The resultant BCI gives a numerical value reflecting the extent the community is impacted by these perturbation related factors. The higher the CTQa, the greater the community is dominated by more tolerant taxa with high TQ values. This is usually accompanied by an elimination of the more fragile taxa with low TQ values.

APPLICATION AND VERIFICATION

Management Priorities

In preparing a management plan for a number of streams, such as on a National Forest, a priority sequence must be established due to limited man-power and economic resources. Those streams that produce the greatest return per unit of management resource expended should receive the highest management priority. Management efforts fall under two approaches: (1) maintaining existing resource quality; and (2) improving existing resources to a state nearer a desired condition.

Stream management is basically directed at maintaining or improving the physical habitat and/or water quality so the stream can support a quality sport fishery. If a stream has quality habitat and a plentiful macroinvertebrate food base, a fishery should flourish.

Physical habitat is relatively easy to measure and manage compared to water quality. A stream with marginal habitat but a good supply of high quality water should respond well biologically to habitat improvement, and at a reasonable resource expenditure. A stream with good habitat but poor water quality will usually require considerable resource expenditure before any significant improvement in the biota of the stream is realized. A stream with good water quality should receive a higher management priority rating than one with poor water quality because it will require less costly management.

Aquatic macroinvertebrates are excellent indicators of water quality as it relates to the needs of aquatic biota including fish. When the macroinvertebrate community is in good condition, it can be assumed that water quality is adequate for a healthy fishery also. Therefore, top management priority should be given streams with good physical habitat plus a healthy macroinvertebrate community. Next highest priority would go to streams with less than desirable habitat, but a healthy macroinvertebrate community. This strategy is summarized below:

Management Priority	Habitat Quality	Biotic Condition
1.	high-moderate	high
2.	high-moderate	moderate
3.	low	high-moderate
4.	high-moderate	low
5.	low	low

Of course if a stream starts to drop in either habitat quality or biotic condition, immediate action should be taken to determine the cause and stop the perturbation.

Determining Biotic Condition and Trend

Using 2 stations on the West Fork of the Duchesne River, Duchesne County, Utah, one above and one below the Vat Diversion as examples, the following will illustrate the use of the Biotic Condition Index (BCI). These 2 stations have habitat survey, water quality, and macroinvertebrate data available for 1977 and 1978.

Above the Vat Diversion the stream is lined with dense shrubs and grass, the stream substrates are dominated by rubble and gravel, gradient averages 1.5 percent, total alkalinity ranges between 150 and 190 mg/*l* $CaCO_3$ and sulfates rarely exceed 35 mg/*l*. From Table 6 we find this station has an expected mean community tolerance quotient of 50 (CTQp).

Below Vat Diversion the stream is lined with evergreen trees, shrubs, and grass, stream substrates are dominated by rubble and boulders, average stream gradient is 2.0%, total alkalinity ranges between 150 and 190 mg/*l* $CaCO_3$, and sulfates rarely exceed 35 mg/*l*. Thus, a predicted community tolerance quotient of 50 also (Table 6).

Tables 7 and 8 give the results of macroinvertebrate samplings, twice in 1977 and once in 1978. Results are given as the mean number of organisms/m^2 for each listed taxon. Also given are tolerance quotients (described in Figure 6 and Tables 1, 2, 3, and 4) for each taxon. These TQ's were taken from Table 5. CTQa is the arithmetic mean of the tolerance quotients. Four samples were taken each date from each station using a modified Surber Sampler (Figure 10). Analysis of variance between samples is given as the standard deviation and coefficient of variation. Two dominance diversity indices were calculated for each set of samples, $\bar{d}$ (Shannon-Weaver Index) and H (Brillouin's Index).

Above Vat Diversion (Table 7) there were numerous taxa collected (36) the spring of 1977. The number of taxa was reduced to 32 by November 1977 and only 30 were collected the spring of 1978. Numbers per m^2 were high during 1977 (45,410 in March and 58,237 in November) but numbers were much lower in April 1978 (16,288/m^2). The dominance diversity indices did not reflect this community change. The CTQa showed an elimination of fragile species resulting in an overall increase in the community tolerance quotient. The Biotic Condition Index (BCI) showed an overall reduction in community condition from 110% of expected to only 81%.

Below Vat Diversion (Table 8) there were 40 taxa in March 1977 but the number had dropped to only 29 by November and was still at 29 in April 1978. The dominance diversity indices ($\bar{d}$ and H) failed to reflect any community change during 1977 and showed only a slight change by April 1978. The CTQa showed no change in mean community tolerance between March and November 1977, but by April 1978 a significant increase was evident. This indicates the reduction in taxa was accounted more by elimination of the "clean water" species than the more tolerant taxa. The BCI indicates an excellent system in 1977 with the community 98-103% of expected. Between November 2, 1977, and April 28, 1978, a deterioration in community structure occurred with the BCI dropping to only 87.7% of expected.

The drops in BCI at both stations between November 2, 1977, and April 28, 1978, could be the result of several factors possibly including substrate scouring by anchor ice, or early spring runoff. Benthic communities do go through cyclical highs and lows relating to natural conditions such as amount of precipitation and runoff, temperature, irregular storm related floods, etc. The most

probable cause of the decreased BCI was the drought of 1977 with below average stream flows the fall of 1977 and winter of 1977-78. Increased sedimentation and/or anchor ice due to reduced flows (water velocities) would have stressed the community. If this was the cause, the increased water flows of 1978-1979 should have allowed community recovery. Analysis of 1978-1979 samples will be required to verify these conjectures. The results in Tables 7 and 8 are not definitive of an actual impact but they raise a red flag of warning. This stream should be closely monitored for 2 or 3 years more and from the results obtained, correct management action should be taken.

In order for accurate analyses of macroinvertebrate samples, definite support data needs to be gathered at the time of sampling. Figure 11 is an example of a possible field record sheet showing the needed information. Occular estimates of substrate composition and riparian vegetation are adequate but water quality—sulfate and alkalinity—should be measured using standard methods. Water discharge is usually available from existing records.

STREAM RATING USING THE BIOTIC CONDITION INDEX (BCI)

Step 1. Fill out field form (Figure 11) for study - extract: gradient _____%; substrate dominance Bo _____, Ru _____, Gr _____, Sa/Si _____; total alkalinity _____ mg/*l*; and sulfate _____ mg/*l*.

Step 2. Using the information on field form and the key provided in Table 6, determine a predicted community tolerance quotient (CTQp) for study stream. CTQp = _____.

Step 3. Take 3 or 4 quantitative macroinvertebrate samples; have them processed by a reputable laboratory; and obtain a list of taxa with tolerance quotients (TQ) for each taxon listed (Table 5).

Step 4. Sum the TQ's and divide by the number of TQ's to get an actual community tolerance quotient (CTQa).

$$\frac{\sum_{1}^{n} TQ}{n} = CTQa \qquad CTQa = _____$$

Step 5. Determine Biotic Condition Index (BCI) by:

$$\frac{CTQp}{CTQa} \times 100 = BCI \qquad _____ \times 100 = _____$$

Step 6. Evaluate stream habitat value using established methods - channel, banks, riparian zone. Habitat value high _____, moderate _____, or low _____.

Step 7. Establish a stream condition rating and a management strategy from the following table:

Condition	Management Strategy	Habitat Quality	CTQa	BCI
1	maintain high quality	high	<65	>85
2	habitat improvement	high-moderate	65-80	70-85
3	habitat improvement	low	<80	>70
4	water quality improvement	high-moderate	>80	<70
5	habitat and water quality improvement	low	>80	<70

CONCLUSIONS

The Biotic Condition Index (BCI): (1) is sensitive to all types of environmental stress; (2) is applicable to various types of streams; (3) gives a linear assessment from unstressed to highly stressed conditions; (4) is independent of sample size providing the sample contains a representative assemblage of species; (5) is based on data readily available or easily acquired; and (6) meshes readily with, and supports existing stream habitat and/or water quality management programs.

FIGURES

		Page
Figure 1.	Relationship of number of taxa represented at each site to alkalinity ($CaCO_3$ equivalents)	17
Figure 2.	Relationship of number of taxa represented at each site to sulfate (SO_4)	17
Figure 3.	Relationship of number of taxa represented at each site to percent gradient (transformed)	17
Figure 4.	Relationship of number of taxa represented at each site to substrate dominance index	18
Figure 5.	Site index (log transformed) regressed with number of taxa	18
Figure 6.	Relationship between mean macroinvertebrate density (number/m^2 $\pm$ 1 standard deviation) and total alkalinity of stream water	19
Figure 7.	Relationship between mean dry weight of aquatic macroinvertebrates (gm/m^2 $\pm$ standard deviation) and total alkalinity of stream water	20
Figure 8.	Transformed values given various levels of total alkalinity, sulfate, gradient, and substrate	21
Figure 9.	Jaccard Similarity Index cluster dendrogram of 54 selected macroinvertebrate taxa clustered against 65 stream stations	22
Figure 10.	Modified Surber Sampler (Winget, 1970)	23
Figure 11.	Sample of field record sheet to be filled out for each stream station to be sampled for macroinvertebrates	24

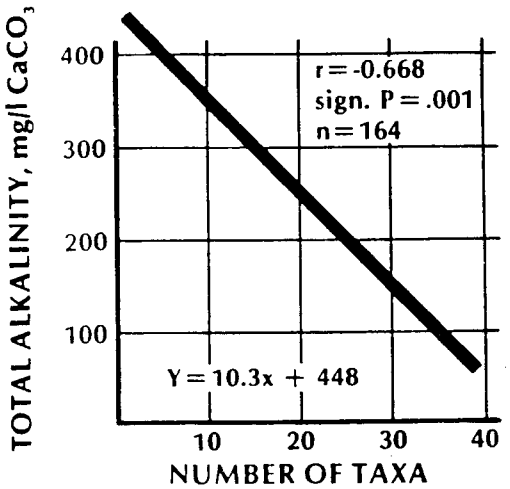


Figure 1. Relationship of Number of Taxa Represented at each site to Alkalinity ($CaCO_3$ equivalents).

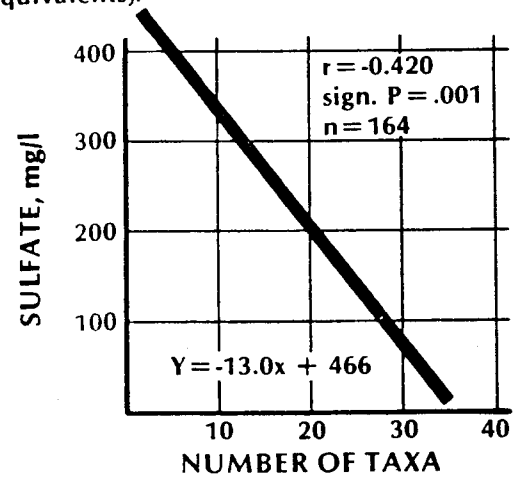
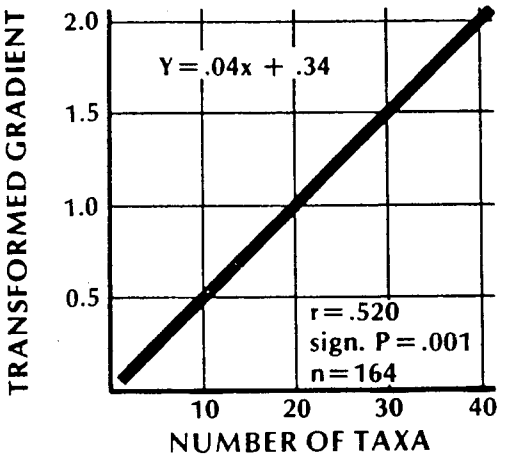
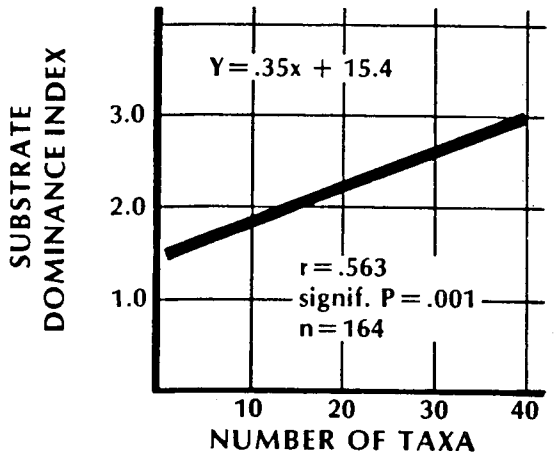


Figure 2. Relationship of Number of Taxa Represented at each site to Sulfate (SO_4).



% Grad.	Transformed
0-0.4	0
0.5-0.8	1
0.9-1.2	1.5
1.3-3.0	2.0
3.1-3.5	1.8
3.6-4.0	1.5
4.1-4.5	1.0
4.6-5.0	0.8

Figure 3. Relationship of Number of Taxa Represented at each site to Percent Gradient (Transformed).



Substrate Dominance Index a+b+c			
Substrate Type	Order of Dominance 1 a	2 b	3 c
Boulder	2.0	1.5	1.0
Rubble	2.0	1.5	1.0
Gravel	0.5	0.7	1.0
Sand/Silt	0	0.5	1.0

Figure 4. Relationship of Number of Taxa Represented at each site to Substrate Dominance Index.

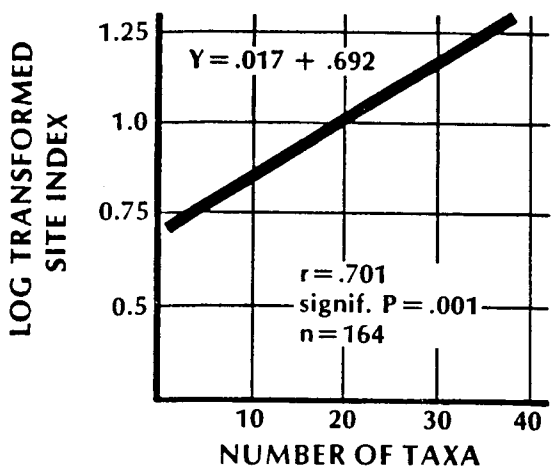


Figure 5. Site Index (Log Transformed) Regressed with Number of Taxa. Alkalinity, sulfate, substrate, and gradient transformed values were summed for each data set, the log of each taken and regressed against number of taxa.

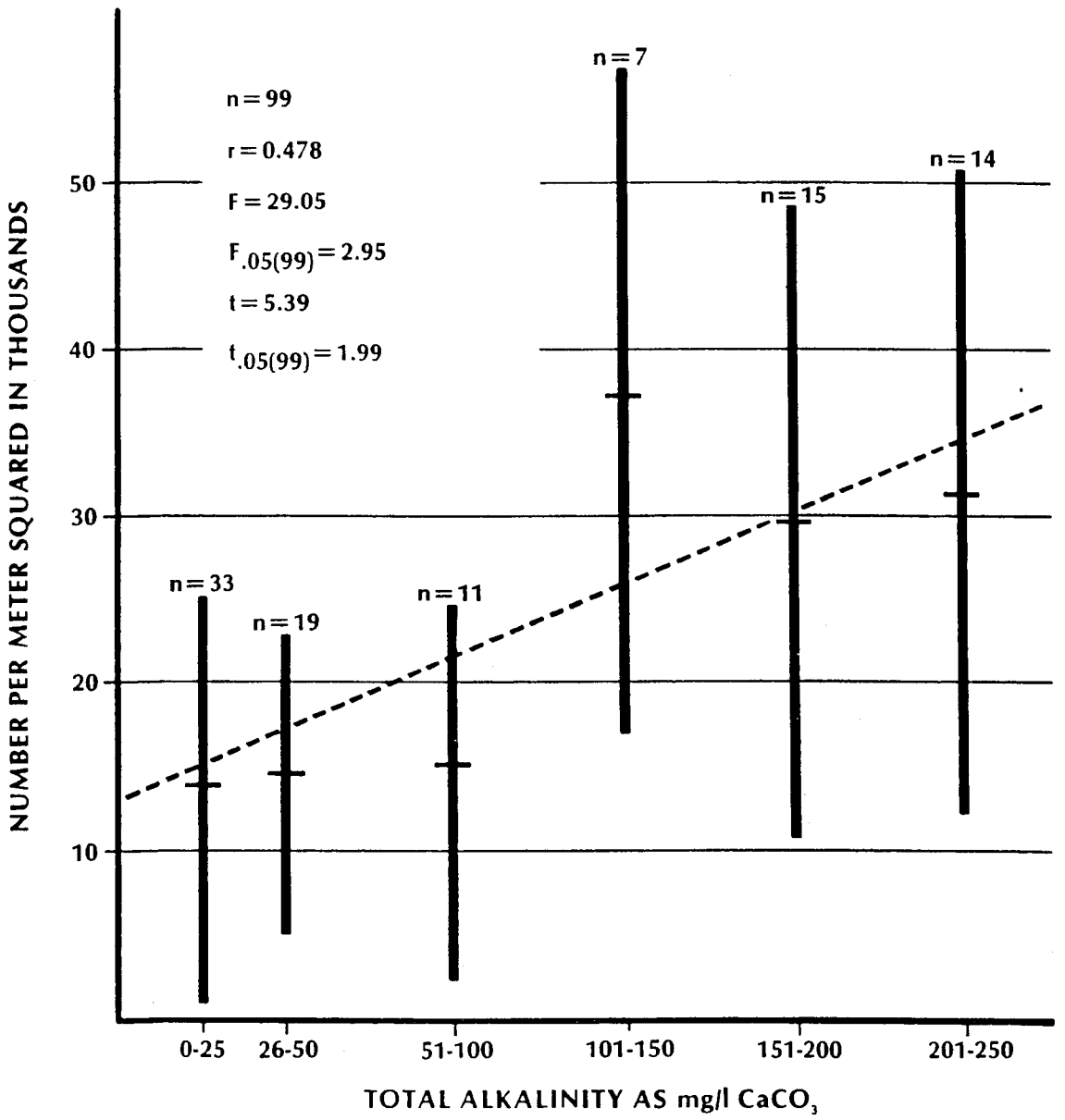


Figure 6. Relationship between mean macroinvertebrate density (number/m² ± 1 standard deviation) and total alkalinity of stream water.

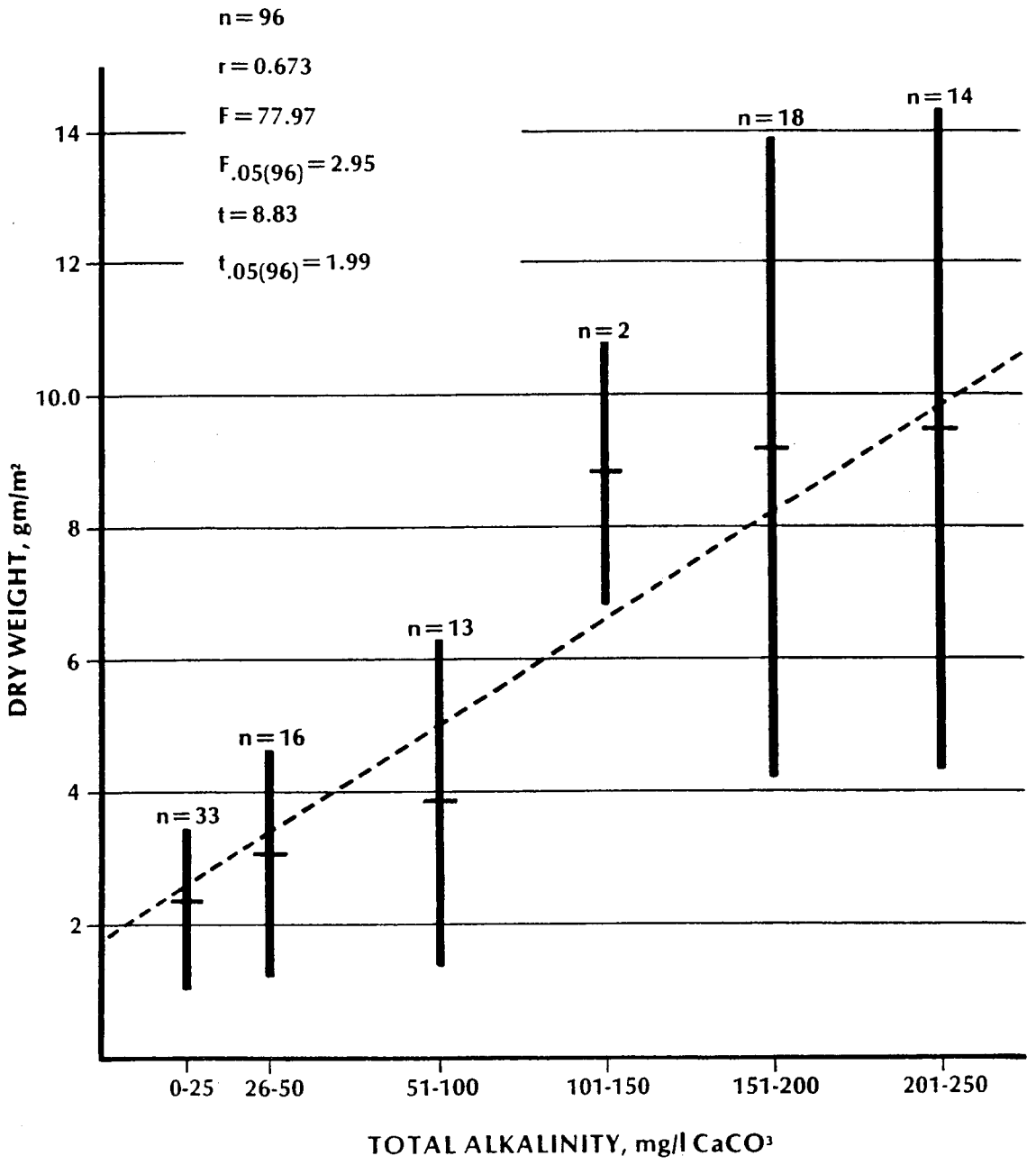


Figure 7. Relationship between mean dry weight of aquatic macroinvertebrates (gm/m² ± 1 standard deviation) and total alkalinity of stream water.

(a) Total alkalinity as mg/l $CaCO_3$

0-199	200-300	> 300

Increasing Environmental Tolerance

1	2	3

(b) Sulfate as mg/l SO_4

0-149	150-300	> 300

Increasing Environmental Tolerance

1	2	3

(c) Substrate (ASTM Designation D422, 1961 revision) include 2 dominant types. Numbers in parentheses are substrate materials diameter.

boulder (>30.4cm)	rubble (30.4-7.6cm)	gravel (7.5-0.5cm)	sand/silt (<0.5cm)

Increasing Environmental Tolerance

1	2	3	4

(d) Stream gradient

>3.0%	1.3-3.0%	<1.3%

Increasing Environmental Tolerance

1	2	3

Figure 8. Transformed values given various levels of total alkalinity, sulfate, gradient, and substrate. These values are used in calculating tolerance quotients for macroinvertebrates found living under a given set or range of environmental conditions.

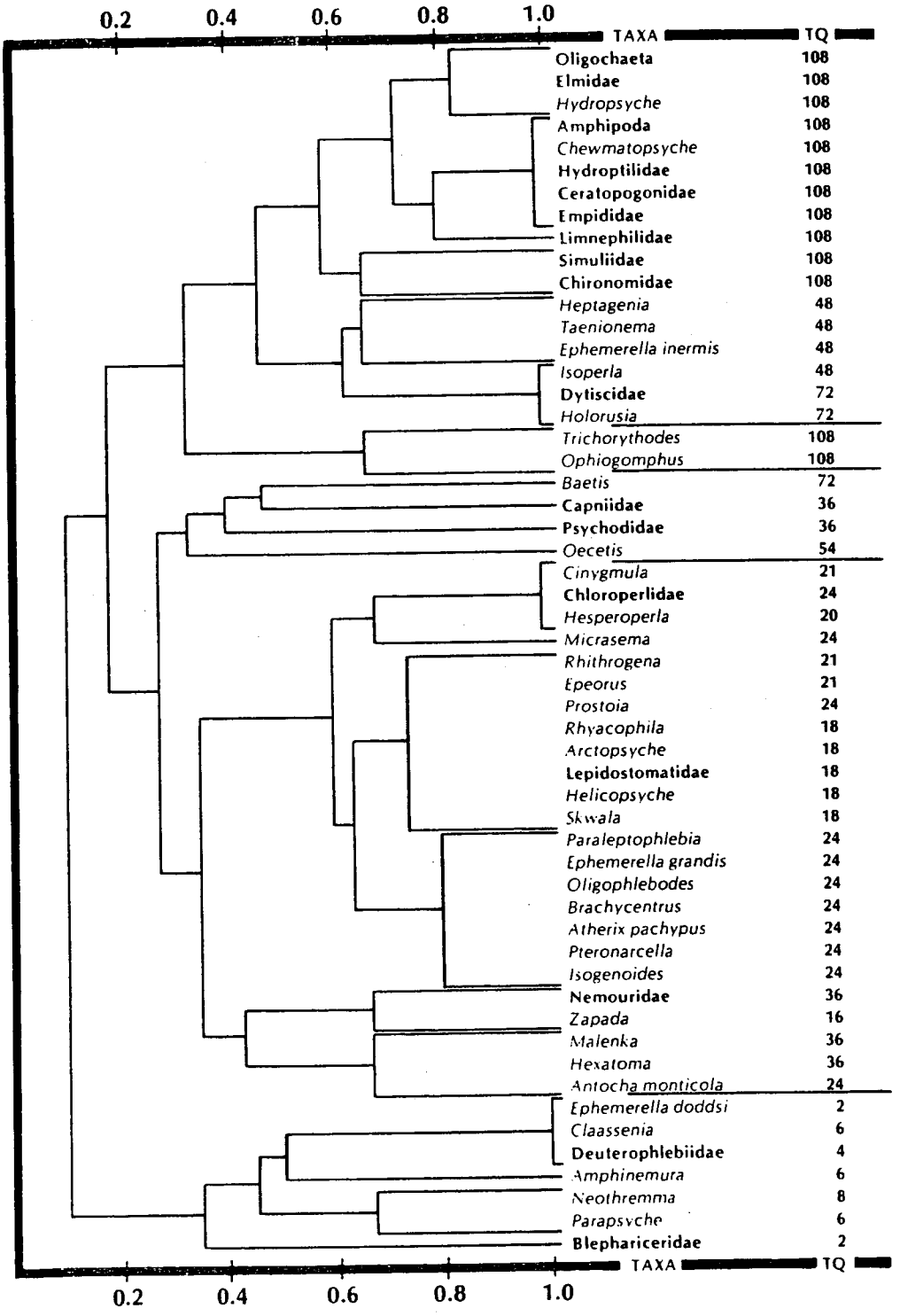


Figure 9. Jaccard Similarity Index cluster dendogram of 54 selected macroinvertebrate taxa clustered against 65 stream stations. Tolerance Quotients (TQ) are given for each taxon showing close similarity between TQ's of each clustered group.

MODIFIED SURBER SAMPLER (WINGET, 1970)

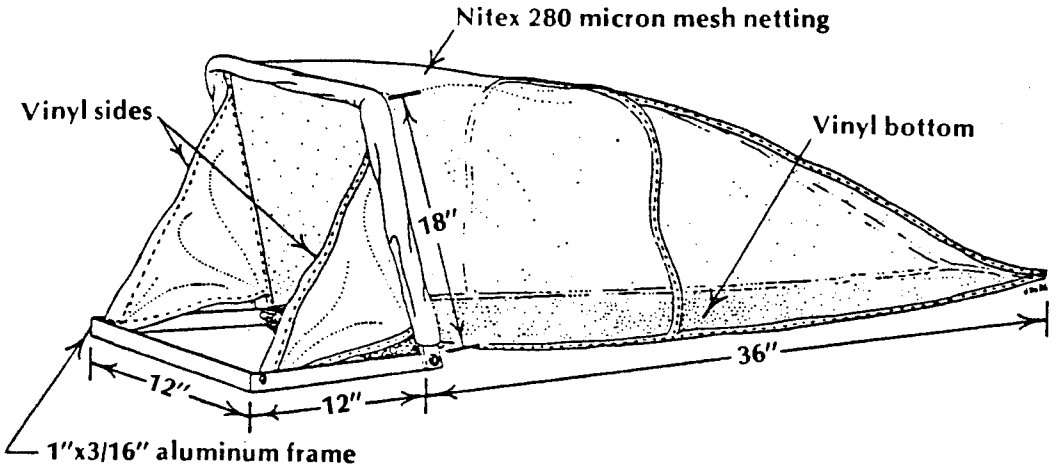


Figure 10. Benthic samples were taken with a Surber sampler (Surber, 1937), modified by Winget (1971) as shown. The intake opening is 30 cm (12 inches) wide by 45 cm (18 inches) high and the bag is 91 cm (3 feet) long. The standard Surber sampler is only 30 cm (12 inches) high with a 62 cm (2 feet) long bag. The modified sampler was designed with a larger collecting bag to prevent excessive backwash and loss of contents when collecting in deep, swift streams.

Figure 11. Sample of field record sheet to be filled out for each stream station to be sampled for macroinvertebrates.

Station Location

State_____ County _____ Drainage _____

Stream _____

Location _____

Elevation _____ ft. and/or _____m.

General Environment

Mean gradient, stream channel _____%

Substrate composition:

Boulder_____%

Rubble _____%

Gravel _____%

Sand/silt _____%

Riparian vegetation:

Evergreen trees _____%

Deciduous trees _____%

Brush/shrubs _____%

Grasses/herbs _____%

Bare soil _____%

Land uses_____

_____

_____

Water uses _____

_____

_____

Water quality:

Mean total alkalinity _____mg/l $CaCO_3$

Mean sulfate _____mg/l

Water clear _____, slightly cloudy _____, turbid _____.

Water discharge:

Mean summer flow (July/Aug) _____cfs.

Mean daily or monthly low flow _____cfs.

TABLES

		Page
Table 1.	Number of stations in which *Ephemerella grandis* occurred with specified ranges of alkalinity, sulfate, substrates, and gradient	26
Table 2.	Number of stations in which *Ephemerella doddsi* occurred with specified ranges of alkalinity, sulfate, substrates, and gradient	27
Table 3.	Number of stations in which *Cheumatopsyche* occurred with specified ranges of alkalinity, sulfate, substrates, and gradient	28
Table 4.	Number of stations in which *Brachycentrus* occurred with specified ranges of alkalinity, sulfate, substrates, and gradient	29
Table 5.	Tolerance Quotients of Aquatic Macroinvertebrates based upon tolerance to alkalinity, sulfate, and sedimentation including low stream gradients	30
Table 6.	A key giving Predicted Community Tolerance Quotients (CTQp) for various combinations of gradient (%), substrates, total alkalinity (mg/*l* $CaCO_3$), and sulfate (mg/*l* SO_4) for any given stream	38
Table 7.	Macroinvertebrate community description for West Fork Duchesne River above Vat Diversion, 1977 and 1978	42
Table 8.	Macroinvertebrate community description for West Fork Duchesne River below Vat Diversion, 1977 and 1978	44

Table 1. Number of stations in which *Ephemerella grandis* occurred with specified ranges of alkalinity, sulfate, substrates, and gradient. Ranked by mean number of *E. grandis* per meter square. A total of 164 stations were analyzed.

	Alkalinity mg/l (TOTAL)			Sulfate mg/l SO_4		
Density	0-199 (1)	200-299 (2)	300 (3)	0-149 (1)	150-300 (2)	300 (3)
1-100	43	9	1	53	0	0
101-200	8	2	1	11	0	0
210-500	6	7	0	13	0	0
501-1,000	5	8	0	13	0	0
1,001-2,000	1	4	0	5	0	0
2,001-3,045	2	4	0	6	0	0
TOTAL	65	34	2	101	0	0

	Gradient %			Substrate (use highest number included in top two dominant substrate types)		
Density	3.0% (1)	1.3-3.0 (2)	1.3 (3)	Rubble (2)	Gravel (3)	Sand/Silt (4)
1-100	11	29	13	31	16	6
101-200	0	8	3	8	2	2
201-500	0	9	4	2	7	4
501-1,000	0	10	5	5	2	6
1,001-2,000	0	4	1	1	4	0
2,001-3,045	0	5	1	1	2	3
TOTAL	11	65	27	48	33	21

Tolerance Quotient = alkalinity x sulfate x gradient x substrate

TQ = 2x1x3x4
= 24

Table 2. Number of stations in which *Ephemerella doddsi* occurred with specified ranges of alkalinity, sulfate, substrates, and gradient. Ranked by mean number of *E. doddsi* per meter square. A total of 164 stations were analyzed.

	Alkalinity mg/*l*			Sulfate mg/*l*		
	0-199	200-299	300	0-149	150-300	300
Density	(1)	(2)	(3)	(1)	(2)	(3)
1-30	18	0	0	18	0	0
31-70	11	0	0	11	0	0
71-130	7	0	0	7	0	0
131-200	5	0	0	5	0	0
200-301	1	0	0	1	0	0
TOTAL	42	0	0	42	0	0

	Gradient %			Substrate (use highest number included in top two dominant substrate types)		
	3.0%	1.3-3.0	1.3	Rubble	Gravel	Sand/Silt
Density	(1)	(2)	(3)	(2)	(3)	(4)
1-30	1	13	4	16	2	0
31-70	3	5	2	10	0	0
71-130	0	7	0	6	1	0
131-200	0	4	1	5	0	0
200-301	0	1	0	1	0	0
TOTAL	4	30	7	38	3	0

Tolerance Quotient = alkalinity x sulfate x gradient x substrate

$$TQ = 1x1x2x2$$
$$= 4$$

Table 3. Number of stations in which *Cheumatopsyche* occurred with specified ranges of alkalinity, sulfate, substrates, and gradient. Ranked by mean number of *Cheumatopsyche* per meter square. A total of 164 stations were analyzed.

	Alkalinity mg/*l* (TOTAL)			Sulfate mg/*l* SO_4		
	0-199	200-299	300	0-149	150-300	300
Density	(1)	(2)	(3)	(1)	(2)	(3)
1-50	8	3	1	8	3	1
51-150	3	1	0	2	1	1
151-500	0	3	3	2	0	4
501-1,500	0	1	1	1	0	1
1,501-5,000	0	2	4	1	0	5
5,001-11,793	0	0	1	0	0	1
TOTAL	11	10	10	14	4	13

	Gradient %			Substrate (use highest number included in top two dominant substrate types)		
	3.0%	1.3-3.0	1.3	Rubble	Gravel	Sand/Silt
Density	(1)	(2)	(3)	(2)	(3)	(4)
1-50	0	6	6	5	2	5
51-150	0	2	2	0	1	3
151-500	0	1	5	1	1	4
501-1,500	0	1	1	1	0	1
1,501-5,000	0	1	5	2	0	4
5,001-11,793	0	0	1	0	0	1
TOTAL	0	11	20	9	4	18

Tolerance Quotient = alkalinity x sulfate x gradient x substrate

TQ = 3x3x3x4
= 108

Table 4. Number of stations in which *Brachycentrus* occurred with specified ranges of alkalinity, sulfate, substrates, and gradient. Ranked by mean number of *Brachycentrus* per meter square. A total of 164 stations were analyzed.

	Alkalinity mg/l (TOTAL)			Sulfate mg/l SO_4		
Density	0-199 (1)	200-299 (2)	300 (3)	0-149 (1)	150-300 (2)	300 (3)
1-100	12	7	4	19	1	3
101-500	17	6	1	24	0	0
501-1,500	20	5	0	25	0	0
1,500-3,000	10	6	0	16	0	0
3,001-6,000	7	7	0	14	0	0
6,001-11,427	5	5	0	10	0	0
TOTAL	71	36	5	108	1	3

	Gradient %			Substrate (use highest number included in top two dominant substrate types)		
Density	3.0% (1)	1.3-3.0 (2)	1.3 (3)	Rubble (2)	Gravel (3)	Sand/Silt (4)
1-100	5	10	8	4	10	9
101-500	0	14	9	14	4	5
501-1,500	0	17	8	18	3	4
1,500-3,000	0	11	5	7	5	4
3,001-6,000	0	10	4	6	6	2
6,001-11,427	0	8	2	3	5	2
TOTAL	5	70	36	52	33	26

Tolerance Quotient = alkalinity x sulfate x gradient x substrate

TQ = 2x1x3x4
= 24

Table 5. Tolerance Quotients of Aquatic Macroinvertebrates based upon tolerance to alkalinity, sulfate, and sedimentation including low stream gradients.

Taxa	TQ
Phylum Coelenterata	108
Class Hydrozoa	108
Phylum Aschelminthes	108
Class Nematoda	108
Phylum Mollusca	108
Class Gastropoda	108
Family Lymnaidae	108
Lymnaea	108
Family Physidae	108
Physa	108
Family Planorbidae	108
Phylum Annelida	108
Class Hirudinea	108
Class Oligochaeta	108
Family Tubificidae	108
Tubifex	108
Family Lumbricidae	108
Lumbricus aquaticus	108
Phylum Platyhelminthes	
Class Turbellaria	108
Order Tricladida	108
Phylum Arthropoda	
Class Arachnida	
Suborder Hydracarina	108
Class Crustacea	108
Order Isopoda	108
Family Asellidae	108
Asellus	108
Order Amphipoda	108
Family Talitridae	108
Hyalella azteca	108
Family Gammaridae	108
Gammarus lacustris	108
Order Decapoda	108
Family Astacidae	108
Pacifastacus gambeli	108
Cambarus laevis	108
Order Cladocera	108
Daphnia	108
Order Copepoda	108
Order Ostracoda	108
Class Insecta	108
Order Collembola	108
Family Poduridae	108
Podura aquatica	108
Family Entomobryidae	108

Table 5. Cont.

Taxa	TQ
Order Megaloptera	72
Family Sialidae	72
Sialis	72
Family Corydalidae	72
Corydalus cognata	72
Order Lepidoptera	72
Family Pyralidae	72
Paragyractis kearfottalis	72
Order Ephemeroptera	72
Family Siphlonuridae	72
Ameletus	48
Siphlonurus occidentalis	72
Isonychia	48
Family Baetidae	72
Baetis spp.	72
Callibaetis	72
Pseudocloeon	72
Centroptilum	36
Dactylobaetis	36
Paracloeodes	72
Family Oligoneuriidae	36
Lachlania saskatchewanensis	36
Homeoneuria	36
Family Heptageniidae	48
Heptagenia	48
Stenonema	48
Cinygmula	21
Rhithrogena	21
Epeorus	21
Anepeorus	48
Family Leptophlebiidae	36
Paraleptophlebia	24
Leptophlebia	24
Choroterpes	36
Traverella	36
Family Tricorythidae	108
Tricorythodes	108
Leptohyphes	72
Family Ephemerellidae	48
Ephemerella	48
Ephemerella grandis	24
Ephemerella doddsi	4
Ephemerella coloradensis	18
Ephemerella tibialis	24
Ephemerella inermis	48
Ephemerella infrequens	48
Ephemerella spinifera	24
Family Ephemeridae	36
Ephemera simulans	36
Hexagenia limbata	36

Table 5. Cont.

Taxa	TQ
Family Caenidae	72
Caenis	72
Brachycerus	72
Family Polymitarcidae	48
Ephoron	48
Order Odonata	
Family Cordulegastridae	72
Cordulegaster	72
Family Gomphidae	108
Gomphus	108
Erpetogomphus compositus	72
Ophiogomphus severus	108
Progomphus borealis	72
Family Aeshnidae	72
Aeshna	72
Anax	72
Oplonaeschna	72
Family Libellulidae	72
Cordulia shurtleffi	72
Erythemis	72
Leucorrhinia	72
Libellula	72
Sympetrum	72
Somatochlora	72
Family Agrionidae	108
Hetaerina americana	108
Calopteryx	108
Family Lestidae	108
Archilestes	108
Lestes	108
Family Coenagrionidae	108
Argia	108
Amphiagrion	72
Enallagma	72
Ischnura	72
Coenagrion	72
Telebasis salva	72
Order Hemiptera	
Family Belastomatidae	72
Belastoma	72
Benacus	72
Lethocerus	72
Abedus	72
Family Corixidae	108
Callicorixa	108
Hesperocorixa	108
Corisella	108
Trichocorixa	108
Cenocorixa	108
Graptocorixa	108
Arctocorixa	108
Sigara	108

Table 5. Cont.

Taxa	TQ
Family Gerridae	72
Gerris	72
Rheumatobates	72
Family Naucoridae	72
Ambrysus mormon	72
Pelocoris	72
Family Notonectidae	108
Notonecta	108
Buenoa	108
Family Veliidae	72
Microvelia americana	72
Rhagovelia distincta	72
Family Mesoveliidae	72
Mesovelia	72
Family Macroveliidae	72
Macrovelia	72
Order Plecoptera	
Family Nemouridae	36
Amphinemura	6
Malenka	36
Prostoia besametsa	24
Podmosta	12
Zapada	16
Nemoura	24
Family Capniidae	32
Capnia	32
Eucapnopsis	18
Isocapnia	24
Mesocapnia frisoni	32
Utacapnia	18
Family Taeniopterygidae	48
Taenionema	48
Doddsia	24
Oemopteryx	48
Family Leuctridae	18
Paraleuctra	18
Perlomymia	18
Family Pteronarcyidae	24
Pteronarcella badia	24
Pteronarcys californica	18
Pteronarcys princeps	24
Family Perlodidae	48
Megarcys signata	24
Skwala parallela	18
Cultus aestivalis	12
Isogenoides	24
I. elongatus	24
I. zionensis	24
Kogotus modestus	18
Pictetiella expansa	18
Diura knowltoni	24
Isoperla	48

Table 5. Cont.

Taxa	TQ
Family Perlodidae (Cont.)	
I. ebria	24
I. fulva	48
I. mormona	48
I. quinquepunctata	48
Family Chloroperlidae	24
Family Perlidae	24
Acroneuria abnormis	6
Claassenia sabulosa	6
Hesperoperla pacifica	18
Perlesta placida	24
Doronuria theodora	18
Order Trichoptera	
Family Rhyacophilidae	18
Rhyacophila	18
Atopsyche	18
Himalopsyche	18
Family Glossosomatidae	32
Glossosoma	24
Anagapetus	24
Protoptila	32
Culoptila	32
Family Philopotamidae	24
Chimarra	24
Doliphilodes (sortosa)	24
Wormaldia	24
Family Psychomyidae	108
Polycentropus	108
Nyctiophylax	108
Psychomyia	108
Tinodes	108
Family Hydropsychidae	108
Hydropsyche	108
Cheumatopsyche	108
Arctopsyche	18
Smicridea	72
Diplectrona	48
Macronema	48
Parapsyche	6
Family Hydroptilidae	108
Hydroptila	108
Agraylea	108
Ochrotrichia	108
Stactobiella	108
Neotrichia	108
Ithytrichia	108
Oxyethira	108
Leucotrichia	108
Alisotrichia	108
Mayatrichia	108
Family Limnephilidae	108
Limnephilus	108
Dicosmoecus	24
Hesperophylax	108

Table 5. Cont.

Taxa	TQ
Family Limnephilidae (Cont.)	
Oligophlebodes	24
Apatania	18
Amphicosmoecus	18
Neothremma	8
Lenarchus	18
Chyranda	18
Psychoglypha	24
Ecclisomyia	24
Homophylax	18
Allocosmoecus	18
Asynarchus	108
Clistorania	108
Grammotaulius	108
Imania	48
Neophylax	24
Onocosmoecus	18
Pycnopsyche	72
Family Leptoceridae	54
Oecetis	54
Leptocella	54
Triaenodes	54
Mystacides	54
Ceraclea	54
Family Lepidostomatidae	18
Lepidostoma	18
Family Brachycentridae	24
Brachycentrus	24
Micrasema	24
Oligoplectrum	24
Amiocentrus	24
Family Helicopsychidae	18
Helicopsyche borealis	18
Family Polycentropodidae	72
Polycentropus	72
Nictiophylax	72
Family Sericostomatidae	72
Gumaga	72
Order Coleoptera	
Family Haliplidae	54
Brychius	54
Haliplus	54
Peltodytes	54
Family Dytiscidae	72
Derovatellus	72
Laccophilus	72
Bidessus	72
Agabus	72
Hygrotus	72
Hydroporous	72
Oreodytes	72

Table 5. Cont.

Taxa	TQ
Family Dytiscidae (Cont.)	
Ilybius	72
Rhantus	72
Dytiscus	72
Acilius	72
Cybister	72
Deronectes	72
Thermonectus	72
Coptotomus	72
Family Hydrophilidae	72
Helophorous	72
Hydrochara	72
Berosus	72
Enochrus	72
Hydrophilus	72
Tropisternus	72
Hydrobius	72
Paracymus	72
Crenitis	72
Ametor	72
Helochares	72
Laccobius	72
Enochrous	72
Cymbiodyta	72
Family Elmidae	108
Zaitzevia	
Narpus	
Stenelmis	
Dubiraphia	
Optioservus	108
Heterlimnius	
Elmis	
Simsonia	
Microcylloepus	
Lara	
Family Cyrinidae	108
Gyrinus	108
Family Amphizoidae	24
Amphizoa	24
Family Hydraenidae	72
Order Diptera	
Family Tipulidae	72
Antocha monticola	24
Dicranota	24
Hexatoma	36
Holorusia grandis	72
Helobia	36
Tipula	36
Family Psychodidae	36
Maruina	36
Psychoda	36
Pericoma	36

Table 5. Cont.

Taxa	TQ
Family Blephariceridae	2
Bibiocephala grandis	2
Agathon	2
Family Deuterophlebiibae	4
Deuterophlebia coloradensis	4
Family Culicidae	108
Aedes	108
Culex	108
Anopheles	108
Mansonia	108
Psorophora	108
Culiseta	108
Family Dixidae	108
Dixa	108
Family Simuliidae	108
Family Chironomidae	108
Family Ceratopogonidae	108
Family Stratiomyidae	108
Euparyphus	108
Family Tabanidae	108
Tabanus	108
Family Rhagionidae	24
Atherix pachypus	24
Family Dolichopodidae	108
Family Empididae	108
Hemerodromia	108
Family Ephydridae	108
Ephydra	108
Family Muscidae	108
Limnophora	108
Family Syrphidae	108
Chrysogastera	108
Tubifera	108
Helophilus	108

Table 6. A key giving Predicted Community Tolerance Quotients (CTQp) for various combinations of gradient (%), substrates, total alkalinity (mg/l $CaCO_3$), and sulfate (mg/l SO_4) for any given stream.

	Go to Key No.	CTQp
1. Stream Gradient 0.1-1.2	2	
1.3-3.0	15	
>3.0	28	
2. Substrate Mostly Boulder & Rubble	3	
Gravel & Rubble	7	
Sand & Boulder, Rubble or Gravel	11	
3. Total Alkalinity 0-199	4	
200-300	5	
>300	6	
4. Sulfate 0-149		51
150-300		71
>300		90
5. Sulfate 0-149		53
150-300		71
>300		90
6. Sulfate 0-149		90
150-300		96
>300		108
7. Total Alkalinity 0-199	8	
200-300	9	
>300	10	
8. Sulfate 0-149		53
150-300		85
>300		103
9. Sulfate 0-149		55
150-300		86
>300		103
10. Sulfate 0-149		89
150-300		97
>300		108
11. Total Alkalinity 0-199		12
200-300		13
>300		14
12. Sulfate 0-149		60
150-300		90
>300		108

Table 6. Cont.

	Go to Key No.	CTQp
13. Sulfate 0-149		60
150-300		90
>300		108
14. Sulfate 0-149		90
150-300		99
>300		108
15. Substrate Mostly Boulder & Rubble	16	
Gravel & Rubble	20	
Sand & Boulder, Rubble or Gravel	24	
16. Total Alkalinity 0-199	17	
200-300	18	
>300	19	
17. Sulfate 0-149		50
150-300		65
>300		90
18. Sulfate 0-149		50
150-300		65
>300		90
19. Sulfate 0-149		90
150-300		96
>300		108
20. Total Alkalinity 0-199	21	
200-300	22	
>300	23	
21. Sulfate 0-149		50
150-300		80
>300		103
22. Sulfate 0-149		55
150-300		80
>300		108
23. Sulfate 0-149		80
150-300		96
>300		108
24. Total Alkalinity 0-199	25	
200-300	26	
>300	27	

Table 6. Cont.

	Go to Key No.	CTQp
25. Sulfate 0-149		66
150-300		88
>300		108
26. Sulfate 0-149		65
150-300		88
>300		108
27. Sulfate 0-149		85
150-300		93
>300		108
28. Substrate Mostly Boulder & Rubble	29	
Gravel & Rubble	33	
Sand & Boulder, Rubble or Gravel	37	
29. Total Alkalinity 0-199	30	
200-300	31	
>300	32	
30. Sulfate 0-149		50
150-300		62
>300		100
31. Sulfate 0-149		50
150-300		62
>300		108
32. Sulfate 0-149		85
150-300		90
>300		108
33. Total Alkalinity 0-199	34	
200-300	35	
>300	36	
34. Sulfate 0-149		50
150-300		77
>300		108
35. Sulfate 0-149		50
150-300		77
>300		108
36. Sulfate 0-149		90
150-300		99
>300		108
37. Total Alkalinity 0-199	38	
200-300	39	
>300	40	

Table 6. Cont.

		Go to Key No.	CTQp
38.	Sulfate 0-149		80
	150-300		100
	>300		108
39.	Sulfate 0-149		80
	150-300		100
	>300		108
40.	Sulfate 0-149		100
	150-300		108
	>300		108

Table 7. Macroinvertebrate community description for West Fork Duchesne River above Vat Diversion, 1977 and 1978.

Taxa	Mean Number/m² 22 Mar 1977	2 Nov 1977	28 Apr 1978	TQ
Nematoda	22	-	151	108
Oligochaeta	337	2,324	2,206	108
Turbellaria	-	323	43	108
Hydracarina	2,676	5,315	1,291	108
Ostracoda	-	516	237	108
Ephemeroptera				
Baetis spp.	3,214	3,400	301	72
Cinygmula sp.	947	2,130	441	21
Epeorus sp.	409	43	97	21
Heptagenia sp.	495	-	-	48
Rhithrogena sp.	43	22	-	21
Paraleptophlebia sp.	7	-	-	24
Tricorythodes minutus	7	-	22	108
Ephemerella doddsi	65	-	-	2
E. grandis	248	2,389	420	24
E. inermis	732	3,034	237	48
Plecoptera				
Pteronarcella badia	86	43	-	24
Prostoia besametsa	2,468	516	11	24
Zapada haysi	22	-	-	16
Paraleuctra sp.	7	-	-	18
Eucapnopsis krercauda	29	-	22	32
Diura knowltoni	14	-	-	24
Isoperla fulva	158	581	-	48
Skwala parallela	-	65	-	18
Chloroperlidae	50	215	-	24
Trichoptera				
Brachycentrus sp.	545	8,500	2,938	24
Micrasema sp.	108	-	-	24
Glossosoma sp.	50	108	140	24
Arctopsyche sp.	682	280	22	18
Cheumatopsyche sp.	-	-	43	108
Hydropsyche sp.	-	280	32	108
Oligophlebodes sp.	10,204	2,044	1,345	24
Hesperophylax sp.	-	22	172	108
Neothremma sp.	-	-	22	8
Lepidostoma sp.	-	65	-	18
Rhyacophila sp.	610	86	-	18
Hydroptilidae	14	-	-	108
Coleoptera				
Elmidae	136	624	290	108
Diptera				
Eriocera sp.	29	22	46	36
Holorusia grandis	-	3	3	72
Antocha monticola	8,981	6,284	807	24
Dicranota sp.	14	-	11	24
Pericoma sp.	452	129	43	36
Simuliidae	-	22	-	108
Chironomidae	11,262	18,572	4,691	108

Table 7. Cont.

Taxa	Mean Number/m² 22 Mar 1977	2 Nov 1977	28 Apr 1978	TQ
Diptera (Cont.)				
Ceratopogonidae	-	-	43	108
Empididae	208	258	161	108
Atherix pachypus	43	22	-	24
mean number/m²	45,410	58,237	16,288	
standard deviation	16,166	25,741	5,587	
coefficient of var.	35.6	44.2	34.3	
mean dry weight, gm/m²	15.8	29.7	10.4	
number of taxa	36	32	30	
$\bar{d}$ (Shannon-Weaver)	3.19	3.32	3.32	
H (Brillouin)	3.16	3.29	3.30	
CTQ_a	45.3	54.5	61.7	
CTQ_p	50	50	50	
BCI	110.4	91.7	81.0	

Table 8. Macroinvertebrate community description for West Fork Duchesne River below Vat Diversion, 1977 and 1978.

Taxa	Mean Number/m² 22 Mar 1977	2 Nov 1977	28 Apr 1978	TQ
Nematoda	-	22	22	108
Oligochaeta	304	603	237	108
Turbellaria	19	-	75	108
Hydracarina	2,276	3,562	1,754	108
Collembola	43	-	-	108
Ephemeroptera				
Baetis spp.	425	742	183	72
Cinygmula sp.	551	1,065	301	21
Epeorus sp.	334	22	65	21
Heptagenia sp.	11	-	-	48
Rhithrogena sp.	24	22	11	21
Ephemerella doddsi	3	-	-	2
E. grandis	153	1,194	118	24
E. inermis	422	1,076	269	48
Plecoptera				
Pteronarcella badia	14	183	3	24
Prostoia besametsa	401	97	11	24
Zapada haysi	11	-	-	16
Skwala parallela	-	65	-	18
Isoperla fulva	92	97	-	48
Diura knowtoni	22	-	-	24
Paraleuctra sp.	22	-	-	18
Capniidae	11	-	-	32
Chloroperlidae	100	172	65	24
Trichoptera				
Brachycentrus sp.	409	4,476	699	24
Micrasema sp.	65	32	22	24
Glossosoma sp.	117	22	-	24
Helicopsyche borealis	-	-	11	18
Arctopsyche sp.	342	151	3	18
Hydropsyche sp.	118	387	-	108
Lepidostoma sp.	43	452	172	18
Hydroptila sp.	-	-	11	108
Oligophlebodes sp.	1,891	65	678	24
Hesperophylax sp.	-	-	54	108
Rhyacophila sp.	86	-	-	18
Coleoptera				
Elmidae	22	22	248	108
Hydraenidae	-	-	32	72
Dryopidae	-	420	-	54
Diptera				
Tipulidae	11	-	-	72
Antocha monticola	468	1,625	828	24
Eriocena sp.	24	22	118	36
Tipula sp.	32	-	-	36
Pericoma sp.	242	129	22	36
Simuliidae	32	-	-	108
Chironomidae	3,946	2,378	3,325	108

Table 8. Cont.

Taxa	Mean Number/m² 22 Mar 1977	2 Nov 1977	28 Apr 1978	TQ
Diptera (Cont.)				
Ceratopogonidae	27	-	22	108
Dolichopodidae	30	-	-	108
Empididae	54	129	65	108
Atherix pachypus	32	151	-	24
mean number/m²	13,229	19,383	9,424	
standard deviation	8,744	11,300	6,069	
coefficient of var.	66.1	58.5	64.4	
mean dry weight, gm/m²	5.8	13.3	4.2	
number of taxa	40	29	29	
$\bar{d}$ (Shannon-Weaver)	3.64	3.55	3.20	
H (Brillouin)	3.61	3.53	3.17	
CTQ_a	50.9	48.5	57.0	
CTQ_p	50	50	50	
BCI	98.2	103.1	87.7	

REFERENCES CITED

Altman, P. L. and D. S. Dittmer. 1966. Environmental Biology. Federation of American Societies for Experimental Biology. 694 pp.

American Fisheries Society. 1967. A Symposium on Water Quality Criteria to Protect Aquatic Life. AFS No. 4—Supplement to 96(11). 37 pp.

_____. 1976a. Instream Flow Needs, Vol. I. Ed. J. F. Osborn and C. H. Allman. 551 pp.

_____. 1976b. Instream Flow Needs, Vol. II. Ed. J. F. Osborn and C. H. Allman. 657 pp.

Armitage, K. B. 1958. Ecology of the riffle insects of the Firehole River, Wyoming. Ecology 39(4):571-580.

Austin, M. P. and I. Noy-Meir. 1971. The problem of non-linearity in ordination experiments with two-gradient models. J. Ecol. 59:763-773.

Bakke, B. M. 1977. Grazing is destroying our fish. Conserv. Feb.-Mar. pp. 31-34.

Barber, W. E. and N. R. Kevern. 1973. Ecological factors influencing macroinvertebrate standing crop distribution. Hydrobiologia 43(1-2):53-75.

Baumann, R. W., A. R. Gaufin, and R. F. Surdick. 1977. The Stoneflies (Plecoptera) of the Rocky Mountains. Memoirs of Amer. Entomol. Soc. No. 31. 208 pp.

Beck, W. M. 1954. Studies in stream pollution biology: I. A simplified ecological classification of organisms. Quatr. J. of Fla. Acad. of Sci. 17(4):221-227.

_____. 1955. Suggested method for reporting biotic data. Sewage and Indust. Wastes. 27(10):1193-1197.

Bell, H. L. 1969. Effect of substrate types on aquatic insect distribution. Minn. Acad. of Sci., J. 35(2-3).

Brillouin, L. 1960. Science and Information Theory. 2nd ed. Academic Press, Inc. New York, N.Y. 320 pp.

Brusven, M. A. and K. V. Prather. 1974. Influence of stream sediments on distribution of macrobenthos. J. Ent. Soc. British Columbia 71:24-32.

Cairns, J. Jr. 1970. New concepts for managing aquatic life systems. Water Poll. Contr. Fed., J. 42(1):77-82.

Cairns, J. Jr. 1973. Rapid biological monitoring system for determining aquatic community structure in receiving systems. Biological Methods for the Assessment of Water Quality. ASTM STP 528. Amer. Soc. for Test. and Mater. pp. 148-163.

_____. 1977. Aquatic ecosystem assimilative capacity. Fisheries 2(2):5-7.

_____, **and K. L. Dickson.** 1971. A simple method for the biological assessment of the effects of waste discharges on aquatic bottom-dwelling organisms. Water Poll. Contr. Fed., J. 43(5):755-772.

_____, **K. L. Dickson, and E. E. Herricks.** 1975. Recovery and Restoration of Damaged Ecosystems. Univ. Press of Va. ISBN 0-8139-0676-8. 531 pp.

_____, **K. L. Dickson, and G. R. Lanza.** 1973. Rapid biological monitoring system for determining aquatic community structure in receiving systems. Biological Methods for the Assessment of Water Quality. ASTM STP 528. Amer. Soc. for Test. and Mater. pp. 148-163.

_____, **G. R. Lanza, R. E. Sparks, and W. T. Waller.** 1973. Developing biological information systems for water quality management. Water Resources Bull. 9(1):81-99.

Chandler, J. R. 1970. A biological approach to water quality management. Water Poll. Contr. 4:415-422.

Chutter, F. M. 1969. The effects of silt and sand on the invertebrate fauna of streams and rivers. Hydrobiologia 34:57-75.

Colwell, R. K. and D. J. Futuyma. 1971. On the measurement of niche breadth and overlap. Ecology 52(4):567-576.

Cook, S. E. 1976. Quest for an index of community structure sensitive to water pollution. Environ. Poll. 11:269-288.

Cummins, K. W. 1966. A review of stream ecology with special emphasis on organism-substrate relationships. p. 2-51 in Cummins, K. W., C. A. Tryon, and R. T. Hartman eds. Organism-Substrate Relationships in Streams. Spec. Publ. Pymatuning Lab. of Ecology, Univ. of Pittsburgh 4:1-145.

_____. 1973. The utilization of leaf litter by stream detritivores. Ecology 54(2):336-345.

_____. 1974. Structure and function of stream ecosystems. Bio. Sci. 24(11):631-641.

DeMarch, B. G. E. 1976. Spatial and temporal patterns in macrobenthic stream diversity. Fish. Res. Bd. Can., J. 33:1261-1270.

DeJong, T. M. 1975. A comparison of three diversity indices based on their components of richness and evenness. Oikos 26:222-227.

Duff, D. 1975. Biological water quality monitoring and surveillance guidelines for fisheries and aquatic habitat management. Draft, USBLM, Utah State Office, S.L.C., Utah. 40 pp.

Egglishaw, H. J. 1968. The quantitative relationship between bottom fauna and plant detritus in streams of different calcium concentrations. J. Appl. Ecol. 5:731-740.

Erman, D. C., J. D. Newbold, and K. B. Roby. 1977. Evaluation of streamside bufferstrips for protecting aquatic organisms. Dept. of Forestry. and Conserv., Univ. of Cal. Berkeley. Unpublished report.

Fasham, J. J. R. 1977. A comparison of nonmetric multidimensional scaling, principal components and reciprocal averaging for the ordination of simulated coenoclines, and coenoclines. Ecology 58:551-561.

Ghetti, P. F. and G. Bonazzi. 1977. A comparison between various criteria for the interpretation of biological data in the analysis of the quality of running water. Water Res. 11:819-831.

Glass, G. V., P. D. Peckham, and J. R. Sanders. 1972. Consequences of failure to meet assumptions underlying the fixed effects analyses of variance and covariance. Rev. Educ. Res. 42:237-288.

Green, R. H. 1979. Sampling design and statistical methods for environmental biologists. John Wiley and Sons. 251 + xi pp.

Halfon, E. 1979. Theoretical systems ecology, advances and case studies. Academic Press, New York. 516 + xiv pp.

Harrel, R. C. and T. C. Dorris. 1968. Stream order, morphometry, physico-chemical conditions, and community structure of benthic macroinvertebrates in an intermittent stream system. Am. Midl. Nat. 80(1):220-251.

Hart, D. S. and M. A. Brusven. 1976. Comparison of benthic insect communities in six small Idaho Batholith streams. Melanderia 23:2-18.

Hart, C. W. and S. L. Fuller, ed. 1974. Pollution ecology of freshwater invertebrates. Academic Press, Inc., New York. ISBN 0-12-324850-3. 384 pp.

Hendricks, A., D. Henley, J. T. Wyatt, K. L. Dickson, and J. K. G. Silvey. 1974. Utilization of diversity indices in evaluating the effect of a paper mill effluent on bottom fauna. Hydrobiologia 44:463-474.

Hoehn, R. C., J. R. Stauffer, M. Masnik, and C. H. Hocutt. 1974. Relationships between sediment oil concentrations and the macroinvertebrates present in a small stream following an oil spill. Environ. Letter 7(4):354-352.

Hooper, D. R. 1973. Evaluation of the effects of flows on trout stream ecology. Dept. of Engineer. Res. Pacific Gas & Electric Co., Emeryville, CA. 94608. 97 pp.

Hunt, R. L. 1976. A long-term evaluation of trout habitat development and its relation to improving management-related research. Amer. Fish. Soc., Trans. 105(3):361-364.

Hynes, H. B. N. 1971. The biology of polluted waters. Univ. of Toronto Press, Toronto. 202 pp.

_____. 1972. The ecology of running waters. Univ of Toronto Press, Toronto. 555 pp.

Jones, S. 1972. Silt pollution: a new term for an old problem. Mo. Conserv. pp. 4-7.

Kendall, D. G. 1975. The recovery of structure from fragmentary information. Phil. Trans. Roy. Soc. A279:547-582.

Kolkwitz, R. and M. Marsson. 1908. Verichte der Deutschen Batenischen Gesselschaft 26:505-519. Translation in: Biol. of Water Poll., USDI, Fed. Water Poll. Contr. Assoc. 1967.

_____. 1909. Ecology of animal saprobia. Int. Rev. of Hydrobiology and Hydrogeography 2:126-152. Translation in: Biol. of Water Poll., USDI, Fed. Water Poll. Contr. Assoc. 1967.

LaFrance, C. R. 1972. Sampling and ordination characteristics of computer-simulated individualistic communities. Ecology 53:387-397.

Lewins, R. 1966. The strategy of model building in population biology. Amer. Sci. 54:421-431.

Lloyd, M. and R. J. Ghelhardi. 1964. A table for calculating the "equitability" component of species diversity. J. Anim. Ecol. 33:217-225.

Luedtke, R. J., M. A. Brusven, and F. J. Watts. 1976. Benthic insect community changes in relation to in-stream alterations of a sediment-polluted stream. Melanderia 23:21-39.

Macan, T. T. 1974. Freshwater ecology. John Wiley and Sons, New York. 343 pp.

MacKay, D. W., P. G. Soulsby, and T. Poodle. 1973. The biological assessment of pollution in streams. Assoc. of River Auth. Yr. Bk. and Direct., London. pp. 189-197.

Margaleff, D. R. 1958. Information theory in ecology. General Systems 3:36-71.

Masnik, M. T., J. R. Stauffer, C. H. Hocutt, and Wilson. 1976. The effects of an oil spill on the macroinvertebrates and fish in a small south-western Virginia creek. J. Environ. Sci. Health. All (4 & 5):281-296.

Mathis, B. J. 1965. Community structure of benthic macroinvertebrates in an intermittent stream receiving oil field brines. Unpubl. Ph.D. Thesis, Oklahoma State Univ., Stillwater, Okla. 52 pp.

_____. 1968. Species diversity of benthic macroinvertebrates in three mountain streams. Trans. III. Okla. State Acad. Sci. 61:171-176.

Merritt, R. W. and K. W. Cummins. 1978. An introduction to the aquatic insects of North America. Kendall/Hunt Publ. Co. ISBN 0-8403-1813-8. 441 pp.

Mosteller, F. and R. E. K. Rourke. 1973. Sturdy statistics: Non-parametric and order statistics. Addison-Wesley Publ. Co. Reading, Mass.

Moyle P. B. 1976. Some effects of channelization on the fishes and invertebrates of Rush Creek, Modoc County, California. Calif. Fish and Game 62(3):179-186.

Noy-Meir, I. and M. P. Austin. 1970. Principal component ordination and simulated vegetational data. Ecology 51:551-552.

Nuttall, P. M. and J. B. Purves. 1974. Numerical indices applied to the results of a survey of the macroinvertebrate fauna of the Tamar Catchment (Southwestern England). Freshwat. Biol. 4:213-222.

Olive, J. J. 1976. Chemical-physical and biological assessment of water quality in the Cuyahoga River (1973-1974). The Ohio J. of Sci. 76(1):5-15.

Patten, B. C. 1962. Species diversity in net phytoplankton of Rarita Bay. J. Mar. Res. 20:57-75.

Pennak, R. W. 1977. Trophic variables in rocky mountain trout streams. Arch. Hydrobiol. 80(3):253-285.

Pielou, E. C. 1966a. The measurement of diversity in different types of biological collections. J. Theoret. Biol. 13:133-144.

_____. 1966b. The use of information theory in the study of the diversity of biological populations. Proc. Fifth Berkely Symp. Math. Statist. and Probab.

_____. 1966c. Shannon's formula as a measure of specific diversity: its use and misuse. Amer. Naturalist 100:463-465.

Pielou, E. C. 1972. Niche width and niche overlap: a method for measuring them. Ecology 53(4):687-692.

Platts, W. S. 1979. Livestock grazing and riparian/stream ecosystems—an overview. Forum—Grazing and Riparian/Stream Ecosystems. O. B. Cope ed. Trout Unlimited, Inc. pp. 39-45.

Poole, R. W. 1971. The use of factor analysis in modeling natural communities of plants and animals. Ill. Natural Hist. Surv. Biol. Notes No. 72. February 1971. pp. 1-14.

Reice, S. R. 1977. The role of animal associations and current velocity in sediment-specific leaf litter decomposition. Oikos 29:357-365.

Reichert, M. 1973. The use of macroinvertebrates as indicators of water quality. Unpubished M.S. Thesis, Brigham Young University, Provo, Utah. 284 + xvi pp.

Resh, V. H. and J. D. Unzicker. 1975. Water quality monitoring and aquatic organisms: the importance of species identification. Water Poll. Contr. Fed., J. 47(1):9-16.

Ringler, N. H. and J. D. Hall. 1975. Effects of logging on water temperature and dissolved oxygen in spawning beds. Amer. Fish. Soc., Trans. 104(1):111-121.

Shannon, C. E. and W. Weaver. 1963. The mathematical theory of communication. Univ. of Ill. Press. Urbana, Ill.

Skellam, J. G. 1969. Models, inference, and strategy. Biometrika 25:457-475.

Stoneburner, D. L. 1977. Preliminary observations of the aquatic insects of the Smokey Mountains: altitudinal zonation in the spring. Hydrobiologia 56(2):137-143.

Stout, J. and J. Vandermeer. 1975. Comparison of species richness for stream-inhabiting insects in tropical and mid-latitude streams. Amer. Naturalist 109:263-280.

Swan, J. M. A. 1970. An examination of some ordination problems by use of simulated vegetational data. Ecology 51:89-102.

Thomas, W. A. 1976. Attitudes of professionals in water management toward the use of water quality indices. J. of Environ. Manage. 4:325-338.

Ulfstrand, S. 1967. Microdistribution of benthic species (Ephemeroptera, Plecoptera, Trichoptera, Diptera: Simuliidae) in Lapland Streams. Oikos 18:293-310.

Ward, J. V. 1975. Bottom fauna substrate relationships in a northern Colorado trout stream: 1945-1974. Ecology 56:1429-1434.

Watson, V. and O. L. Loucks. 1979. An analysis of turnover times in a lake ecosystem and some implications for system properties. In: Theoretical Systems Ecology. E. Halfon ed. Acad. Press. New York, N.Y. pp. 355-384.

Wiggins, G. B. 1977. Larvae of the North American Caddisfly Genera (Trichoptera). Univ. of Toronto Press, Toronto. ISBN 0-8020-5344-0. 401 pp.

Wilhm, J. L. 1965. Species diversity of benthic macroinvertebrates in a stream receiving domestic and oil refinery effluents. Unpubl. Ph.D. Thesis, Oklahoma State Univ., Stillwater, Okla. 42 pp.

_____. 1967. Use of biomass units in Shannon's formula. Ecology 49(1):153-156.

_____. 1970a. Range of diversity index in benthic macroinvertebrate populations. Water Poll. Contr. Fed., J. 42(5):R221-R224.

_____. 1970b. Effects of sample size on Shannon's formula. Southwest Naturalist 14:441-445.

_____ **and T. C. Dorris.** 1968. Biological parameters for water quality criteria. Bio. Sci. 18:477-481.

Williams, D. D. 1978. Substrate size selection by stream invertebrates and influence of sand. Limnol. and Oceanogr. 23(5)1030-1033.

_____ **and H. B. N. Hynes.** 1976. Stream habitat selection by aerially colonizing invertebrates. Can. J. of Zool. 54(5):685-693.

_____ **and H. B. N. Hynes.** 1977. The ecology of temporary streams II. General remarks on temporary streams. Int. Revue Res. Hydrobiol. 62(1):53-61.

Williams, R. D. and R. N. Winget. 1979. Effects of flow manipulation on macroinvertebrate communities in Strawberry River, Utah, U.S.A. First Internat. Symp. on Regulated Streams. Erie, Pennsylvania. 18-20 April 1979. Sponsored by North Amer. Benthol. Soc. (in press).

Winget, R. N. 1976a. Biological assessment of stream quality in the Uintah Basin Association of Governments Area. Unpub. UBAG Report. Eyring Research Institute. Provo, Utah, 84601. 203 pp.

_____. 1976b. Aquatic habitat inventory in the Hot Desert EIS Area, Utah. Aquatic Ecology Lab, Brigham Young University, Provo, Utah. 84602. 116 pp.

_____. 1977a. Aquatic survey of Birch Creek, Beaver County, Utah, a critical habitat stream on national resource lands affected by livestock. Aquatic Ecology Lab, Brigham Young University, Provo, Utah, 84602. 29 pp.

_____. 1977b. Aquatic survey of Big Creek, Rich County, Utah, a critical habitat stream on national resource lands affected by livestock. Aquatic Ecology Lab, Brigham Young University, Provo, Utah, 84602. 29 pp.

_____. 1977c. Aquatic survey of selected streams with critical habitats on national resource lands affected by livestock and recreation. Aquatic Ecology Lab, Brigham Young University, Provo, Utah, 84602. 117 pp.

Werner, E. E. 1977. Habitat partitioning in a freshwater fish community. Fish. Res. Bd. Can., J. 34(3)360-370.

Zand, S. M. 1976. Indices associated with information theory in water quality. Water Poll. Contr. Fed., J. 48(8)2026-2031.

☆ U.S. GOVERNMENT PRINTING OFFICE: 1980-0-677-133/7