Water quality monitoring and aquatic organisms: the importance of species identification

VINCENT H. RESH AND JOHN D. UNZICKER

Several methods have been used to analyze the effects of human activities on aquatic environments. They include the use of selected chemical and physical parameters, as well as a variety of biological measurements that range from bacteriological analyses to bioassay studies of fish and other aquatic organisms. Although macroinvertebrates are rarely used in bioassay studies, they have proven to be extremely useful in water quality monitoring in two different methods of investigation: studies of community diversity and use as indicator organisms.

The first approach to water quality analysis with macroinvertebrates involves determining the degree of organization that is present in the structure and composition of the component species of the benthic community. These mathematical expressions, termed diversity indexes, are widely used and of great potential value. There are, however, many problems inherent both in the choice of an index and in the interpretation of the meaning of the estimate of organization or diversity index that is calculated.

The second approach involves the use of macroinvertebrates as indicator organisms. While there have been several useful reviews of the literature on the use of indicator organisms, the recent monograph by Sladecek is currently the most comprehensive work on the subject. It is interesting to note that the use of this saprobic or indicator organisms system has been accepted and applied by the majority of hydrobiologists in continental Europe and the Soviet Union. It is only in Great Britain and North America that the indicator organisms system has not received wide acceptance.

Several investigators have cited certain taxonomic groups as characteristic of clean water and others as characteristic of polluted water. Beck developed a biotic index of water quality based on a mathematical comparison of the numbers of organisms that can tolerate no significant amounts of pollution with those that can tolerate moderate amounts. The limitations of arbitrarily assigning entire taxonomic groups (usually family level or above) a tolerant or intolerant designation, as was done in the biotic index and in several other proposed biological formulae are obvious. For instance, not all chironomids or oligochaetes are limited to strictly polluted conditions. In the classic stream pollution recovery pattern, in which the dissolved oxygen (DO) concentration gradually increases from a minimum level in the septic zone of extreme pollution to a higher level in the zone of recovery, certain species in the genera Chironomus and Simulium are among the first insects to appear in the recovery zone. Some species in these genera are also often found only in clean water conditions with a high concentration of DO, however. Even in genera with pollution tolerant species, there often exists a wide range of ecological tolerances that allows organisms that have been taxonomically placed in the same genus to be designated pollution tolerant and pollution intolerant.

The futility of attempting to develop water quality criteria by using indicator organisms that have been identified only to the generic level is illustrated in Table 1.
In this table, the genera of aquatic macroinvertebrates for which water quality tolerances have been established for more than a single species (of a particular genus) are listed according to the arbitrary assignment of the individual species' water quality tolerances. These data are compiled from Table 7 of the Macroinvertebrate Section of Weber. In that review, the index species are classified according to the arbitrary categories of (a) tolerant, "frequently associated with gross organic contamination . . . thriving under anaerobic conditions"; (b) facultative, "frequently associated with moderate levels of organic contamination"; and (c) intolerant, "not found associated with even moderate levels of organic contaminants and . . . intolerant of moderate reductions in dissolved oxygen." Of the 89 genera for which water quality tolerances have been established for more than a single species, the component species fell into different tolerance categories in 61 of the genera examined. The largest group of genera in Table I belong to the category in which some species in the genus were judged tolerant to pollution, others in the same genus were designated intolerant to pollution, and others were classified as facultative with regard to pollution tolerances. This table is a summary of the current state of knowledge concerning indicator organisms, and, perhaps better than any other example, it emphasizes the need for species-level identifications in ascertaining water quality tolerances. Above all else, it signifies the questionable value of the generic-level taxonomic unit as a water quality indicator.

In practice, generic identifications have to be made either during the process of arriving at the species identifications or during the process of assessing what material is worth identifying to the specific level (for example, water quality studies). The use of the genus as an end point in identifications is of dubious value, however. For instance, in examining the range of tolerances present in Table I, the number of genera that are either entirely tolerant or intolerant to organic pollution is small when compared with the number of genera containing species with different pollution tolerances. This raises the question of the value of identifying organisms below the family level if the generic level is the most precise level that may be arrived at with any degree of confidence in the accuracy of the determinations.

While it is true that the family-level identification tells us nothing about eco-

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TABLE I.—Benthic macroinvertebrate genera for which water quality tolerances have been established for more than a single species. Column headings indicate tolerant, facultative, and/or intolerant.
logical indicators or water quality, it seems equally true that generic-level identifications will not yield a great deal of additional information and may not be worth the time and effort. In fact, an empirical observation of the diversity in the sample may be all that is needed to draw the same conclusions that are reached after a detailed and costly appraisal made from generic-level identifications.

In most groups of aquatic insects, identification of the immature stages cannot currently be made below the generic level. Unfortunately, it is the immature stage in the life cycle of an aquatic insect that is most commonly encountered by hydrobiologists. Wiggins** pointed out that in one of the best known orders of aquatic insects, the Trichoptera (caddis flies), immature and adult stages have been associated for only 20 percent of the total North American species. Basically, this critical lack of information is the reason why usable larval keys for species-level identifications have not been developed. There have been several keys developed for species-level identifications that are confined to the fauna of a small region or to cases in which associations of immature and adult stages have been made for only a fraction of the species in the genus. These keys are rarely open-ended, that is, by following through the series of choices made in each of the couplets, it is very likely that an identification may be made and may seem correct. If a species-level key were based on information dealing with only a percentage of the species of that genus, however, an incorrect identification might quite easily often be logically determined. Likewise, if the key were based primarily on associations of eastern U. S. species, identifications of specimens from the western U. S. would not likely be correctly determined. In both of the above cases, it would be particularly easy for misidentification to occur if the key were not well illustrated or did not contain an adequate morphological and ecological description that could be used in a final verification of the species-level identification.

Even when associations have been made and species-level identification keys have been constructed, the problem of discovering ecological tolerances for each individual species still exists. Several investigators have attempted to correlate habitats of macroinvertebrates with water chemistry analyses. The major difficulty in using these techniques is that water chemistry parameters may fluctuate widely and rapidly because of temporary pollutional effects or dilution from rainfall, and the component species of the biotic community may better serve as a reflection of past, rather than present, water chemistry conditions.

An alternative approach has been the use of laboratory studies in developing tolerance levels for aquatic insects subjected to environmental stresses, such as heated water, pH, low levels of and extremes in other physical and chemical factors. Gaufin** reported the results of detailed laboratory studies in which the larvae of 20 species of aquatic insects and one species of amphipod were exposed to high water temperatures, low concentrations, and low levels of pH in order to determine their tolerances to these parameters. One problem with the laboratory based technique is that little is known about the maintenance of immature stages of aquatic insects under controlled laboratory conditions and the effect of the stresses of an artificial environment on the organisms themselves. The method has, however, proven effective with certain species and has been used to evaluate their reactions to particular stresses. Difficulties in using the laboratory technique to develop water quality criteria at the species level may arise because of two factors. First, because closely related species may have drastically different water quality tolerances to a particular stress, all species must undergo laboratory testing before a final evaluation can be made. Second, because organisms in nature are subjected to a variety of physical and chemical stresses, there is the possibility that a synergistic effect caused by the interaction of com-

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bined stresses may have a greater influence than either of the two stresses alone.32

With the recent increase in the number of federally and locally funded environmental research projects, the lack of knowledge about the water quality tolerances of aquatic macroinvertebrates and the paucity of identification keys to immature stages of aquatic insects have suddenly become serious problems. These are caused by the demand for consulting services in the identification of aquatic benthos for faunal surveys and the preparation and evaluation of species lists for environmental impact statements. Although emphasized in the literature for many years, the need for keys and basic life history information for aquatic macroinvertebrates is now recognized by a growing number of biologists.

A potentially valuable source of baseline data for a particular area are the specimens that were collected during earlier studies and deposited in university or permanent museum collections. The preparation of any type of environmental inventory or the assessment of an area for an environmental impact statement usually requires a routine search for pertinent available literature on the area to be examined. Rarely are floral and faunal lists published for precise sites that may be proposed for facilities such as nuclear reactor plants or other major construction projects. Museums, however, usually maintain extensive collections that greatly exceed the published records of an area, and catalogues and collection data are often available. Even if the collections are unidentified, they may serve as representative samples of the earlier biota of the area to be examined.

While ichthyologists have occasionally made use of museum collections to examine faunal changes, records of such a procedure being followed by invertebrate zoologists or aquatic entomologists are confined to a single study, that of Starrett.43 Larimore and Smith44 used the fish collections of the Illinois Natural History Survey to illustrate changes in the fish fauna of Champaign County, Ill., over a 60-yr period of urban growth and development in the area. Their conclusions indicate that even with fish, a group far more sensitive to environmental stress than benthic macroinvertebrates, the information that may be derived from a comparison of past and present studies is extremely useful in evaluating pollutional effects on the biological community. The potential value of comparing museum collections with present population is well documented by Starrett's study of Illinois River mussels.

In the following example, water quality tolerances are developed for caddis flies of the genus Athripsodes by using conventional water chemistry techniques, literature reviews, and a reexamination of previous collecting sites to determine temporal faunal changes. This genus was chosen for several reasons. First, the species in it have varied life histories. Second, because of its large size and widespread distribution, it is one of the most frequently collected caddis flies in aquatic surveys. Third, larval and adult associations for species in this genus have also allowed for species-level identifications of the immature stages, and keys have been developed for the eastern North American species.45 While caddis flies have often been regarded as clean water species, several studies27,46 have indicated that many of them may occupy fairly polluted aquatic habitats. It should be emphasized that several features of caddis flies as a group make them particularly useful in studies of this type. These features include the presence of both tolerant and intolerant species, a workable adult taxonomy, and the availability of several successful techniques for the associations of immature and adult stages.47-49

The genus Athripsodes is the sixth largest genus of caddis flies in North America. Many of the approximately 40 species names assigned to the genus may be synonyms. In many preimpoundment surveys, larvae of Athripsodes spp. typically appear in compiled species lists along with other common trichopteran genera such as Cheumatopsyche, Hydropsyche, and Hydroptila. In the genus Athripsodes, the species ancylus, angustus, cancellatus, dilutus, resur-
gens, tarsipunctatus, and transversus are widely distributed over eastern North America, while several additional species seem to be more locally distributed within this range. In establishing larval-adult associations, Athripsodes larvae and pupae have been collected from localities ranging from Ontario to Florida, including small standing pools, large rivers, small glacial lakes, and the Great Lakes.

The A. cancellatus has been reported as being abundant in large rivers such as the St. Lawrence River and the Niagara River. Likewise, A. annulicornis, tarsipunctatus, and transversus are typically found in both large and small rivers. Species such as A. ancylius, dilutus, and flavus are common in small to moderate sized streams, often occurring together in collections. Larvae and pupae of the locally distributed A. nephus inhabit "black water streams" of high tannic content, such as the tributaries of the Suwannee River in Georgia and northern Florida. Larvae of A. slossonae have been collected in the small, slow moving backwaters of a trout stream in Virginia, where the predominant caddis flies were temporary pool limnephilids. The trout stream itself contained numerous larvae of A. dilutus, but no larvae of slossonae were present.

Large lake species include A. erraticus, erullus, saccus, and submacula, which are almost entirely restricted to Lake Erie in their distribution. The presence of these species in collections that were made in the 1930's and deposited in the Entomology Collection at the Ohio State University, Columbus, provided the impetus for the investigation into the current status of these Athripsodes populations. Marshall reported the results of the extensive light trap collections from Lake Erie near Put-in-Bay, Ohio, in 1937. Of the nine species of Athripsodes collected, the following were listed as common: angustus, cancellatus, erullus, resurgens, saccus, and tarsipunctatus. Specimens of A. erraticus that were also collected from Put-in-Bay and are currently in the Ohio State University collections indicate that it was also quite common in Lake Erie during the 1930's.

In a more recent study, Horwath reported the results of extensive black lighting from the same location as Marshall's earlier work. Only four of the original nine species were present: A. angustus, cancellatus, resurgens, and tarsipunctatus. The total numbers collected and the number of collections in which each species appeared were also reduced. Marshall described the abundance of shoreline habitats. These included sandy beaches, shallow bays of mud and vegetation, shores with rubble, and other habitats with large rocks and boulders. The rubble areas with accompanying wave action resembled habitats in stream riffles. The similar substrate types and the diversity of habitats present in this area today indicate that the potential for use by several species of Athripsodes is still present. Undoubtedly, these were the habitats used by the past Lake Erie species. The entire area was examined intensely in 1972 and the only species present were those found in Horwath's 1964 study.

The changes in the Lake Erie mayfly fauna, the aquatic flowering plants, and water chemistry conditions have been well documented. The changes in the caddis fly fauna may also be seen because it seems that the extirpation of four of the common Athripsodes species, erullus, erraticus, saccus, and submacula, from Lake Erie is now complete. The more tolerant species of Athripsodes remain, but in greatly reduced numbers.

Larvae and cases of A. resurgens were first reported from freshwater sponges, probably Spongilla fragilis Leidy, by Kreeker in Put-in-Bay, Lake Erie. Kreeker described the larval case as being made of a parchment-like material in the form of a cone approximately 12 mm in length. Although he identified these specimens as belonging to the family Rhycopodidae, from the description of the case they were undoubtedly Athripsodes, most likely A. resurgens.

With the exception of a single record of a freshwater sponge's encrusting the case of a limnephilid caddis fly, this association of caddis flies and freshwater sponges
is unique to certain species of the genus *Athripsodes*. Several investigators have alluded to the fact that the Spongillidae are extremely intolerant to organic pollution.\(^1\)\(^,{\text{61}}\) Mason et al.,\(^2\)\(^{,\text{62}}\) however, reported the abundance of the chironomid *Xenochironomus xenolabris* in the Ohio River. The larval stage of this midge has also been reported to be dependent on freshwater sponges.\(^3\)\(^,{\text{45}}\)\(^,\text{63, 64}\) The condition of the Ohio River is not the pristine situation that has been described as a typical habitat for the distribution of freshwater sponges. As in the case of *Athripsodes*, this suggests that within the Spongillidae, a wide range of water quality tolerances is also present. Brown,\(^6\)\(^5\) while studying the biology of sponge flies in the family Sisyridae, found the same sponge, *S. fragilis*, in both a cool, clean lake and a warm, polluted pond. Sponges in the lake yielded only larvae of the genus *Climacia*, and sponges in the pond yielded only larvae of the genus *Sisyra*.

Because of the dependence on freshwater sponge, the distribution of the obligate sponge-feeding *Athripsodes* (*angustus, alices, and resurgens*) reflects the micro-habitat distribution of the sponge. Jewell\(^6\)\(^1\) reported ranges of physical and chemical parameters that seem to affect distribution of freshwater sponges within certain habitats. The sponge usually associated with *A. angustus* is *S. lacustris*, although another sponge-feeding larva was reported as *Athripsodes* sp. by Lehmkühl.\(^4\)\(^6\) from the sponge, *Meyenia mulleri*. Fortunately, these specimens were deposited in the collection of the Royal Ontario Museum, Toronto, which enabled the identity of this species to be confirmed at *A. angustus*.

The early collections and detailed field notes of R. E. Richardson\(^1\)\(^8\) at the Illinois Natural History Survey also provided additional data for developing water quality criteria for *Athripsodes* caddis flies. From 1924–27, Richardson made extensive collections with detailed locality descriptions along the length of the Rock River, from northern Illinois to the point at which it eventually empties into the Mississippi River at Rock Island. Additional collections were made by H. H. Ross\(^4\)\(^6\) from several locations along the Rock River during the late 1930's and the early 1940's. From examinations of the collections and locality designations of both early collectors, the localities at which *A. menteitus* were collected in earlier studies could be determined. This species was the dominant leptocerid caddis fly in the collections of Richardson, although he referred to it as *Leptocerus dilatus* in his notes. In 1971 and 1972, the Rock River was examined at four sites where *A. menteitus* was abundant in both series of earlier collections. Neither immature nor adult specimens of this species was found, although large numbers of *A. transversus*, especially rare in Richardson's collections, were collected. In extensive sampling of both larval and adult populations, this was the only species of *Athripsodes* present. In his analysis of Illinois streams, Smith\(^4\)\(^7\) reported that the Rock River contains areas of urbanization and industrialization that contribute to the deterioration of water quality.

A decline in the population of *A. menteitus* may also have occurred in two northern rivers, the St. Lawrence and the Niagara. In reporting on the abundant caddis fly fauna of the St. Lawrence River, Corbet et al.\(^4\)\(^9\) noted the similarity of that fauna to the caddis flies reported in the Niagara River by Munroe.\(^5\)\(^1\) which was based on collections made in the 1940's. Only three species reported from the earlier Niagara River study were not collected in the St. Lawrence River investigations. One species was *A. menteitus*. Two other species were also in the family Leptoceridae.

In reexamining museum collections, there are situations in which a locally distributed species remains unchanged. In the Apple River in northwestern Illinois, *A. flavus* was collected by Ross in the late 1930's. It was collected again in 1972, and a relatively similar population abundance was reported. It must be noted, however, that the Apple River is one of the cleanest and most unchanged streams in Illinois.\(^6\)\(^7\) Unfortunately, there is a paucity of data dealing with laboratory studies on the effect of environmental stress on caddis flies,
particularly *Athripsodes*. Field studies by Roback,\textsuperscript{27} in which water quality tolerances were analyzed by the frequency of occurrence of different caddis fly genera under a specific range of water chemistry conditions, indicate a wide range of tolerances affecting the distribution of species of this genus, however. Representatives of *Athripsodes* were found in rivers and streams with wide ranges of each of the following parameters: methyl orange alkalinity, 20 to 200 mg/l; chloride, 3 to 11 mg/l; carbon dioxide, 5 to 10 mg/l; o$_2$, 1 to 11 mg/l; iron, 0.01 to 1.0 mg/l; total hardness, 10 to 500 mg/l; ammonia, 0.00 to 1.0 mg/l as N; nitrate, 0.03 to 0.7 mg/l as N; pH, 3.0 to 9.0; phosphate, 0.003 to 0.5 mg/l; sulfate, 10 to 90 mg/l; turbidity, 10 to 1,000 units; and biochemical oxygen demand, 0.5 to 1.0 mg/l. The mode within these ranges is usually indicative of a clean water fauna, however. For instance, *Athripsodes* spp. were collected in habitats ranging in DO concentrations from 1 to 11 mg/l, but the mode was 9 mg/l. Similar findings by Scott\textsuperscript{98} for *A. harrisonii* indicate a wide range of tolerances, with this species occurring in habitats in which the pH ranges from 2.8 in acid swamps to 9.2 in alkaline lakes. Even with this range of tolerance of *A. harrisonii* to pH, however, Scott still considers the subfamily Leptocerinae, to which *Athripsodes* belongs, to be the group of trichopterans most sensitive to mild organic or inorganic pollution.

From a consideration of the results of the above field studies and the change in the fauna of the Rock River and Lake Erie, it seems that within the genus *Athripsodes* there is a wide variety of water quality tolerances. The species *A. erraticus*, *erullus*, *menteius*, and *saccus* are less tolerant of pollution than are *A. ancylius*, *cancellatus*, *tarsipunctatus*, or *transversus*. The distributions of the sponge feeding species *A. alicis*, *angustus*, and *resurgens* are intimately linked to the water quality tolerances necessary for the survival of the sponge.

Through associations of immature and adult stages and the development of species-level identification keys, the museum specimens that have been collected in conjunction with extensive water chemistry analysis, such as those studies reported by Roback\textsuperscript{27} and several recent investigators,\textsuperscript{80, 70} will be extremely useful in developing annotations on biological indicator organisms. The technique, used by Roback,\textsuperscript{27} of illustrating the frequency at which different genera appeared within a particular range of water chemistry and physical parameters will be a convenient form for data storage. This will particularly be the case when it is known how these specific abiotic parameters affect, and thus can be assigned to, organisms that have been identified at the species level. When data on an individual species are available over a wide range of conditions, a matrix type of data arrangement that uses a multivariate analysis, such as canonical correlations, will be valuable in using information about water chemistry and biological agents in order to develop a predictive model. A systems analysis approach that employs biological, as well as physical and chemical, data will be extremely useful in examining the possible impacts of proposed actions on aquatic environments.

The macroinvertebrate benthic collections currently being made in the preparation of environmental impact statements are also potentially valuable to the development of workable annotations regarding water quality tolerances at the species level. The most obvious aspect of the importance of the specimens used in preparing these statements is that, in most studies involving macroinvertebrates, water chemistry parameters are measured, along with the benthos, at designated stations. Detailed substrate, vegetation, and geological information is also often combined in studies of potential sites of power plants, dams, or other major civil works activities. Because of the tremendous number of samples taken in conjunction with environmental impact statements, the occurrence of and frequencies at which species appear in certain chemical and physical ranges might provide a great deal of useful information in preparing annotations of water quality tolerances at the species level.
Unfortunately, these collected specimens, often referred to as voucher specimens, are rarely deposited in either museum or major university collections and are not available for general use. Many consulting firms have justified their practice of not maintaining specimens, because they feel either that the clients may prefer to keep all or representative specimens themselves or that after the project has been completed, neither the client nor the consulting firms has any further use for the specimens. Even if collections are kept by the consulting firms, the chances are great that, without the trained personnel necessary to maintain them, the specimens will become desiccated or unusable in some other way and therefore be useless to future researchers.

The advantages of depositing collections at museums or major universities far outweigh any of the possible disadvantages. The specimens would be available for future studies of an area, and they may be extremely valuable in assessing changes, such as is the case with the Lake Erie and Rock River collections that were deposited at Ohio State University and the Illinois Natural History Survey. When specimens are deposited at a museum that has trained curatorial personnel, their value as voucher specimens may be more adequately insured. A third advantage is that the taxonomic expertise that most universities possess would be available to assist in the major identification problems of the consulting firms. Therefore, a long-term cooperative effort of this nature might benefit both the impact statement specialists and the academic taxonomists.

It is not unfeasible to expect consulting firms to pay a fee for curatorial or taxonomic assistance. In the long run, the overhead for voucher specimens maintenance and the difficulty involved in locating taxonomists and specialists would be reduced. These advantages would more than compensate for curatorial and taxonomic assistance fees. For the taxonomists, not only would a cooperative effort with consulting firms increase the size of the collections, but it would also result in specimens with more valuable information, thus making each collection a component in the development of a potential biological indicator organism.

In essence, the authors are suggesting greater cooperation between the consulting industry and academic personnel from which both sides would benefit. The information compiled by the consulting firm will greatly aid both the taxonomist and ecologist in developing water quality criteria that may serve to enhance the true concept of an indicator organism, that is, an understanding of water quality tolerances at the species level.

There is a critical need for increased support of investigations to develop identification keys and resolve basic life history problems of aquatic macroinvertebrates. It is also important that ecological agencies support the programs of taxonomists by collecting data and producing publications. As is illustrated in Table I, biologists are engaging in fruitless exercise if they intend to make any decisions about indicator organisms by operating at the generic level of macroinvertebrate identifications.

The time and effort spent on identifying specimens' genus and in developing endless and often meaningless faunal lists for environmental impact statements should be shifted to associating immature and adult aquatic insects and to developing identification keys. If this were done, the species lists prepared in the future would not merely be taxonomic exercises but valuable tools in the biological assessment of water quality.

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Authors. Vincent H. Resh, formerly with the Water Resources Laboratory, University of Louisville, Ky., is assistant professor of biology, Department of Biology, Ball
State University, Muncie, Ind. John D. Unzicker is assistant taxonomist, Section of Faunistic Surveys and Insect Identification, Illinois Natural History Survey, Urbana, Ill.

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