UNITED STATES · ENVIRONMENTAL PROTECTION AGENCY ·

THE USEFULNESS OF BIOLOGICAL COMMUNITY INDICES FOR ENVIRONMENTAL STANDARDS, CRITERIA, AND ENFORCEMENT - PART I

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NATIONAL ECOLOGICAL RESEARCH LABORATORY
An Associate Laboratory of
National Environmental Research Center—Corvallis

THE USEFULNESS OF BIOLOGICAL COMMUNITY INDICES FOR ENVIRONMENTAL STANDARDS, CRITERIA, AND ENFORCEMENT - PART I

QUESTIONAIRRE SURVEY OF RESEARCHERS AND LITERATURE REVIEW

NATIONAL ECOLOGICAL RESEARCH LABORATORY
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ABSTRACT

An investigation was conducted by written inquiry and a search of relevant literature to determine common criteria for the acceptability and use of biological community parameters, especially indices of species diversity, to enforce pollution regulations in the terrestrial, freshwater, and marine habitats. The investigation revealed that while most respondents from the queried industrial sector, regulatory agencies, and researchers were of the opinion that biological communities were extremely important, there was little agreement on means of measurement. Attempts at application of specific theoretical distributions describing species diversity have given differing results. It is recommended that environmental criteria based on species diversity not be established at the present time.

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SECTION I
CONCLUSIONS

The following conclusions may be drawn with respect to the use of biological community parameters, especially species diversity, for applied, or enforcement criteria:

Although there is a common concern for biological communities among the three major sectors potentially affected by environmental quality criteria, there is little agreement as to how best to numerically express change in community structure. This disagreement is not along associative group lines.

A major obstacle to such agreement is the lack of acceptance of a common definition for the term "community."

"Species diversity" has also been defined and used ambiguously and such ambiguity is not resolved. Recent workers have independently expressed two distinct aspects of species diversity, i.e., species richness and relative distribution among species.

Numbers of species per unit area/volume most meaningfully describes species richness.

Computation of any given index may render a result either consistent or inconsistent with other measures of environmental quality.

If indices of species diversity are to be useful as criteria they must be considered on a case-by-case basis.

Information derived from presently available indices of species diversity is not biologically interpretable.

Information derived from presently available indices of species diversity is not convertible into an economic denominator for derivation of cost versus benefit.

Presently available indices of species diversity do not convey information regarding the esthetic value of biological associations.

Habitat lines drawn as terrestrial, freshwater, or marine, do not relate to the usefulness or lack of usefulness of a given index.

The overwhelming evidence from the survey of opinion by written inquiry and examination of published information in the present undertaking suggests that we are not ready at this time to assign specific magnitudes for specific theoretical distributions as environmental criteria.

SECTION II
RECOMMENDATIONS

It is recommended that presently available indices of species diversity not be used as regulatory criteria.

It is recommended that the information theory formula and equitability component as tabulated by Lloyd and Ghelardi.[49] be computed in on-going U. S. Environmental Protection Agency investigations where good supportive data of other types are collected. The value of these computations would lie in the validation of the indices rather than drawing inferences about environmental quality from index magnitudes.

The U. S. Environmental Protection Agency should adopt a working definition of the biological community. The definition should encompass the total biotic assemblage within physically defined boundaries.

The U. S. Environmental Protection Agency should encourage comparative investigations of the biological community.

SECTION III
INTRODUCTION

In the past decade a plethora of literature has grown up concerning the theoretical and practical value of biological community parameters, especially indices of species diversity, for assessment of environmental well being. Proponents of the use of such indices have emphasized the demonstrated ability to produce a numerical, dimensionless index which retains historical information concerning a biological assemblage and the effects of a pollutant or environmental insult on that assemblage as opposed to physical and chemical indices which reflect only on the instantaneous condition of the environment surrounding the assemblage. Efforts by many investigators have centered on simplifying the calculation of such indices to make possible their estimation and interpretation by persons without a technical biological background. Opponents of the use of species diversity indices are generally not opposed to the concept of species diversity or to the biological community concept, but do express concern that simple number indices of any kind are apt to be misleading in interpretation. Further, there is agreement that confusion exists with respect to the definitions of "communities" and "diversity."

The U. S. Environmental Protection Agency has requested an assessment of the use and acceptance of biological community parameters, especially indices of species diversity, for evaluating environmental change induced by pollution stress and the development of criteria for the use of such indices for enforcement purposes. Battelle Pacific Northwest Laboratories conducted the here-reported preliminary investigation toward the following objectives:

> Determine by written inquiry the acceptability by researchers, by industry, and by government agencies, the use of species diversity indices, alone, or in aggregate, for use as enforcement tools.
>
> Determine by a search of the relevant literature background material on the approaches and uses made of community parameters for environmental assessment.

Assimilate criteria for the use of community parameters, especially species diversity indices, in the terrestrial, freshwater, and marine environments.

Recommend future courses of action for the development of community parameters for environmental assessment and enforcement.

SECTION IV
WRITTEN INQUIRIES

In an effort to ascertain current understanding and level of acceptance of biological community analysis as a measure of environmental change, an inquiry was circulated among persons and groups directly involved with environmental study. To get a reasonable cross section of opinion, we felt it would be appropriate to divide involved groups into three broad classifications: the industrial sector; regulatory agencies; and research groups representing the relevant technical expertise.

An inquiry format was developed which, while somewhat subjective,was felt to be a practical approach to summarizing data obtained from a diverse collection of groups and individuals having widely differing experience with biological communities. We had hoped the format (see Appendix A) was lucid enough to elicit responses from people ranging from those with limited knowledge and understanding of the subject through those who are involved in theory development. That we were able to achieve some measure of success in the above outlined objective is indicated by the large number of thoughtful responses received.

Mailing lists were obtained from indices of ongoing research in relevant fields, of regulatory agencies, and of industries likely to be involved in environmental studies. Copies of the inquiry were mailed to individuals representing each of the three sectors. Three thousand two hundred and twenty-six inquiries were mailed to groups in the United States, Puerto Rico, and Canada.

RESULTS

Ten percent (334) of the respondents completed the inquiries and returned them by the 1 June deadline.

In order to identify a typical respondent we have classified them in three ways. Table 1 lists the associative group, i.e., industrial, regulatory, or research. The column information on the table results from a majority response to the "type of involvement" question. For example, the principal

Table 1. CHARACTERIZATION OF TYPICAL RESPONDENT BY MAJOR GROUP*

	Associative group		
Type of involvement	Industry	Regulatory agency	Research
Section I. Identification			
Principal habitat	Freshwater	Freshwater	Terrestrial
Level of participation	Full time	Full time	Frequent
Understanding	Moderate	Comprehensive	Comprehensive
Position held	Other	Biologist-ecologist	Biologist-ecologist
Years experience	10 or more	10 or more	10 or more
Section II. Type of involvement			
Criteria used	Field survey	Field survey	Field survey
Frequency of environmental assessment	Occasionally	Occasionally	Occasionally
Percent using listed index (one or more)	66%	84%	90%
Section III. Opinion			
Indicator of change	Communities	Communities	Communities
Number of parameters	More than one	More than one	More than one
Recommend for limited training?	No	No	No
Other indices used?	Yes	Yes	Yes
Rating of community analysis	Good	Good	Good

* Characterization derived from percentage response to question of interest. For details see Appendix B.

habitat of most industrial and regulatory respondents was freshwater while the researchers were predominantly terrestrial in specialty. Table 2 characterizes a typical respondent in terms of habitat of principal involvement. A substantial portion of respondents were undecided as to the habitat of principal involvement (see Appendix C for detail). Thus a column for undecided individuals is included. By way of example, from Table 2, terrestrial and freshwater workers reported their frequency of involvement in environmental assessment as occasional; marine workers reported their involvement as frequent; and, the majority of undecided respondents reported they were never involved in environmental assessment. A third classification for respondent characterization, based on years of experience in environmental assessment, is presented on Table 3. Classes were established as zero to two, two to five, five to ten, and greater than ten years. As for characterization by habitat a substantial portion of the respondents were undecided and an appropriate category is included.

In preparation of the inquiry we listed several common indices of species diversity. That part of the inquiry was designed first, to elicit response about the use of those particular indices, and second, to stimulate suggestion of other indicators. There were a few respondents who objected to the approach, but on the whole the response was excellent. Data on the use of the indices listed on our inquiry are presented on Tables 1 to 3 for each of the specific classifications. A selection of additional suggestions by respondents follows:

Method	No. responses
Analysis of variance	1
Organisms/sq.ft.	1
Community metabolism	1
Sequential comparison index	4
Growth rates	1
Serological analysis	1
Long-term study plots	1
Shannon-Wiener H'	8
Successional patterns	1

Table 2. CHARACTERIZATION OF TYPICAL RESPONDENT BY HABITAT OF PRINCIPAL INVOLVEMENT*

	Principal involvement			
Section II. Type of involvement				
Type of involvement	Terrestrial	Freshwater	Marine	Undecided
Criteria used	Field survey	Field survey	Field survey	Field survey
Frequency of environmental	Occasionally	Occasionally	Frequently	Never
Percent using listed index (one or more)	94%	89%	93%	58%
Section III. Opinion				
Indicator of change	Community	Community	Combination	Combination
Number of parameters	More than 1	More than 1	More than 1	More than 1
Recommend for limited training?	No	No	No	No
Other indices used?	Yes	Yes	Yes	Yes
Rating of community analysis	Good	Good	Good	Inconclusive

*For details see Appendix C.

Table 3. CHARACTERIZATION OF TYPICAL RESPONDENT BY NUMBER OF YEARS' EXPERIENCE IN ENVIRONMENTAL ASSESSMENT*

Section II. Type of involvement					
	Years of experience				
Type of involvement	0 - 2	2 - 5	5 - 10	10+	Undecided
Criteria used	Field survey	Field survey	Field survey	Field survey	Inconclusive
Frequency of environmental assessment	Occasionally	Occasionally	Occasionally	Occasionally	Occasionally
Percent using listed index (one or more)	65%	54%	88%	92%	33%
Section III. Opinion					
Indicator of change	Community	Community	Community	Combination	Inconclusive
Number of parameters	More than 1	More than 1	More than 1	More than 1	More than 1
Recommend for limited training?	No	No	No	No	No
Other indices used?	No	Yes	Yes	Yes	Inconclusive
Rating of community analysis	Inconclusive	Good	Good	Good	Good

*Responses falling on a division were elevated to the next higher rank. For details see Appendix D.

Method	No. responses
Direct observation (subjective)	2
Trap-day success	1
Mammalian density	1
Coefficient of similarity 2N/A+B	2
Floristic inventories	2
Cluster analysis	2
Recurrent group analysis	1
Pielou evenness (J)	1
Dissimilarity index	1
Productivity tests	3
Empirical biotic index	1
Sturber - pollution tolerance	1
Trophic index	2
Peterson index	2
Indicator organisms	5
Margalef - chlorophyll ratio	1
Length weight ratio	1
Population structure	1
MacArthur - multiple M	1
Manipulated sample populations	1
Index of faunal affinity	1
Equitability - Lloyd and Ghelardi	1
Ordination analysis	1
Stream drift standing crop	1
Least squares method	1
Paleoecological indicators	1
Rest species increase	1
Community resilence measures	1
Principal component analysis	1
Variance pattern	1
Relative abundance	1

In response to choice of indicators of environmental change, the average number of indicators used by each group are presented in Table 4. For all classifications, a general response is that two or more indicators should be used.

Table 4. AVERAGE NUMBER INDICATORS SELECTED BY RESPONDENTS

Number indicators	Industry		Regulatory agency		Research
	2.3		2.3		2.5
Number indicators	**Terrestrial**		**Fresh**	**Marine**	**Undecided**
	2.7		2.5	2.7	2.5
Number indicators	**0-2**	**2-5**	**5-10**	**10+**	**Undecided**
	3.3	2.0	2.5	2.7	4.0

DISCUSSION

Examination of response data reveals four main conclusions:

The majority of respondents feel they understand what a biological community is.

Most respondents feel community response is the best indicator of environmental change.

There is no general agreement on how to measure community response or what the significance is of the results of indices used.

A substantial portion of respondents expressed doubt that any current index or other numerical expression of community response can replace judgement on the part of the investigator.

With reference to level of understanding of community response the conclusion is derived from a simple tally of responses to direct question. Admittedly there is likely some bias in the result because of a natural desire of the respondents to indicate broad knowledge.

In answering Question 1, Section III, most respondents indicated "the community" is the best indicator of environmental change. The majority of respondents chose more than one indicator.

Many of the respondents wrote marginal remarks, especially on Question 1, Section III: "An indicator of environmental change should be mainly:" Typical responses were:

- All of the above
- It depends on the community
- All of the above and then there is doubt if that is enough
- Change in energy flows
- Site dependent
- ...We need integrated studies, not indicators
- Short term changes may be indicated by chemical analysis and long term by the biological community
- The community is probably the most important, however, chemical analysis and information at the organism and population level is also important
- Should consider lethal and sublethal effects on the organism and population as related to the total community.
- Ecosystem parameters
- Should not be mainly chemical; but should include chemical, community and other biological evaluations as feasible
- Biochemical analyses of tissues of the organism
- Each situation should be assessed - there is no one answer
- No generalization possible or desirable
- Depends on the community (or environment)
- Total systems response
- Freshwater community, taking into consideration entire watershed ecosystem
- Community metabolism
- All 3 (sic) above used with extreme care
- Combination - depending on the type of questions needing answers
- Each area is different and should be treated as a living system with chemical parameters showing the changes and biological the

reasons

- Community is ultimate, but chemistry and the organism are essential to determine early problems and trends

The above-listed comments are in our judgement typical of the subjective comments to the question posed. The inescapable conclusion from these comments is that the respondents feel that ecosystems are far too complex to generalize about in terms of a single numerical index. The great preponderance of respondents encouraged the use of community response in environmental assessment; however, there was little agreement on methods of measurement. Two concepts were stressed to the point of redundancy. First, judgement on the part of the investigator is paramount in evaluating community response. Second, programs must be tailored to individual situations.

SECTION V
LITERATURE

The objective of the here-reported review of literature is not to supplant the many excellent reviews, e.g., Woodwell and Smith[1], Connell and Orias[2], Whittaker[3], MacArthur[4], Pianka[5], and McIntosh[6], concerning the use of species diversity in specific habitats for evaluation of community change. Rather, we attempt to bring together common problems for the establishment of inter-habitat criteria for the assessment by regulatory agencies of potentially deleterious changes brought about by the activities of man.

The biological community, at a point in time, is a reflection of the physical, chemical, and biological components of its history. Insofar as it retains a record of events leading to development, the community, by reason of its integrating, or information retaining ability, forms the basis for an environmental monitoring tool far superior to those methods involving solely the measurement of physical and chemical variables. If one accepts this opening premise, then there are three conditions that must be fulfilled if we are to establish environmental quality criteria in terms of diversity of the biological community. First, we must understand what events in the community's development contribute to the qualitative structure of the community. Second, we must find an adequately concise means of quantitatively expressing the community's qualitative features; and third, we must assign a reasonably derived acceptable level of community development for the criterion. Most of the literature reviewed for this study related to the second of these three conditions.

Even the strongest advocates of using diversity indices as water quality criteria concur that data are needed on specific communities before the usefulness of the index is evident. Thus, Wilhm and Dorris[7] state, "After a particular diversity expression is accepted and a meaningful agreement is found between the natural community and a theoretical distribution, a characteristic diversity value can be found to express the structure of each community." And, later in the same paper they state, "Additional work needs to be done to learn how types and degrees of pollution are expressed in _d_." Cairns and Dickson[8], in presentation of a simple method for biological assessment, state: "Additional work must be done to learn how different types and degrees of pollution are expressed in terms of DI_T."

The term "community" has been defined in a variety of ways. Thus, definitions for community include those which range from a simple assemblage of all the biota at a given location to patterns of natural assemblages having cohesion, and perhaps, culminating in definitions which consider the community as a superorganism. In short, the concept of biological community is generally recognized and accepted but not consistently defined. Further, consistent with Warren's[9] view, our feeling is that pollution is fundamentally a social problem. Hence, the biologist's role becomes that of adequately translating technical descriptions of environmental change into a socially recognizable form. Recommended levels for a particular index or description should relate not to desirability or undesirability but rather to the most accurate description of extant conditions.

The definition of "diversity" is equally clouded in the ecological literature. Example definitions can be found in Hill[10], Pielou[11], Wilhm[12], and Whittaker[3]. Húrlbert[13] states: "Species diversity has been defined in such various and disparate ways that it now conveys no information other than 'something to do with community structure.'"

Nevertheless, those charged with the responsibility of establishing criteria for environmental assessment, or enforcing such criteria, or complying with such criteria must have a common reference. Definitions aside, there does seem to be common agreement that something called a community is extremely important. Arguments relating to the community's status as a level of organization, the degree of interacting functionality, or lack of it, do not seem to detract from the need to monitor and understand the effects of man's activities on biological communities. That communities are important leads us to the position that the U. S. Environmental Protection Agency should adopt a working definition of "community." A common problem, and indeed, one exemplified by EPA[14] is the use of the term community in two different ways in the same paper. Thus on page 16, EPA[14], "Diversity indices are an additional tool for measuring the quality of the environment and the effect of induced stress on the structure of a community of macroinvertebrates" (italics mine). And later, on the same page, "These confounding factors can be reduced by comparing diversity in similar habitats and by exposing artificial substrate samplers long enough for a relatively stable, climax community to develop." (italics mine). The former, limited to a few populations, i.e., the macroinvertebrates, would be hard to visualize as a functional entity. The latter, on the other hand, could readily be visualized in such a manner.

The pragmatic question of what one is measuring when evaluating results from "community" studies is related to the problem of community definition. Thus, thoughtful individuals, e.g., Hill[10], Eberhardt (personal communication), have aptly pointed out that analyses are applied to collections, or samples, and not to natural assemblages. Typically in the literature inferences are drawn about natural assemblages when in fact data are totally lacking to place the samples or collections into perspective with respect to the natural assemblages. Those collections, by inference, are loosely referred to as "communities." We suggest that an interim working definition for community include reference to the total natural assemblage, and for practical purposes, that physically defined limits be placed as boundaries of the defined assemblages. Alternatively, we would propose that the term "community" be dropped entirely from the language of regulations and guidelines.

Indices of species diversity are said to relate to the structure of communities by almost all investigators(Fisher, Corbet, and Williams[15], MacArthur and Wilson[16], Margalef[17], Patten[18], Pianka[5], Pielou[11], Sanders[19], Shannon and Weaver[20], Simpson[21], Whittaker[3], and many others). The biological meaning of the indices initially was closely allied to the relationship between diversity and stability, i.e., the more diverse community is stable; and hence, the community is better adapted. In considering such a relationship, however, one is soon enmeshed in evolutionary time. Thus, from Sanders[19], "It requires appreciable time to evolve a highly diverse fauna, and the time component of our stability-time hypothesis is perhaps best illustrated with lakes. Most lakes are of a relatively transitory nature, or of recent geologic origin. It has been 10,000 years or less since the last glaciation, and the aquatic fauna from such recently glaciated regions shows limited diversification" (italics mine).

Sanders goes on to say that ancient lakes, 30 million years old, are characterized by a highly diverse fauna. The seemingly innumerable biological trials and errors that must have prevailed in the development of a "diverse" fauna are difficult for our imagination to fathom. The "jump" to instantaneous evaluations based on an index, for determination of the effects of a man-related accident or even, in fact, what we commonly call chronic disturbances (several years in duration) does not seem justifiable in terms of a stability related theory. If one accepts the foregoing line of thought then arguments relating to the definition of "diversity" should not muster support from a stability-theoretical base but rather should be rooted in the empirical usefulness of the measure employed. That position is consistent with Hill's[10], discussion of diversity in terms of samples with a total separation from thermal dynamic feedback and information theories.

Eberhardt's[22] position was that an adequate number of theoretical distributions were available but that data on the representativeness of sampling for natural assemblages had received little attention. The Shannon-Wiener function or modification therefrom has received by far the most use both for theoretical and applied purposes. In our view, the index has the distinct disadvantage of being tied inappropriately to: (1) community diversity-stability theory and (2) communication engineering theory. We have already made some statements with respect to the former. With respect to the latter, a comment from Gilbert[23] seems appropriate, "As an engineering subject, information theory has flourished for 18 years because of the promise it gave of improved communication systems. The results are still almost exclusively on paper." Shortly we will present some of the empirical data which have been generated on information theory indices in applied situations but it seems most appropriate to review the salient features in the development of species diversity indices.

In simplest form a diversity index is the ratio of number of species to number of specimens, expressed:

$$S/N$$

where, S = number of species and N = the number of specimens. Large variations in numbers of specimens due to clumping, season, and sample size led quickly to the use of a damping function in the denominator so that the index becomes:

$$d = S-1/\log_e N \text{ or } d = S-1/\sqrt{N}$$

where, d = species richness, and S and N are defined as above.

A table from Wilhm and Dorris[7] aptly illustrates the problem of interpreting values for such an index:

Table 5. THREE HYPOTHETICAL COMMUNITIES HAVING THE SAME NUMBER OF SPECIES (S) AND TOTAL NUMBER OF INDIVIDUALS (N) THAT YIELD THE SAME DIVERSITY INDEX, $\bar{d} = S-1/\log_e N$*

	Individuals in species i (n_i)					Total individuals	Total species
Community	n_1	n_2	n_3	n_4	n_5	N	S
A	20	20	20	20	20	100	5
B	40	30	14	10	5	100	5
C	96	1	1	1	1	100	5

*After Wilhm and Dorris[7]

Wilhm and Dorris[7] correctly point out that the hypothetical communities are very different in structure but that equivalent values are obtained for N, S, and $\bar{d}$. Thus the $\bar{d}$ = species richness, from Margalef[24], becomes recognized as a component of diversity and the need apparently is to devise an index which encompasses other components; most pressing, perhaps, is the component of evenness of distribution of the specimens among the species.

The index of species richness has been shown by numerous authors to increase with increasing sample size and has been criticized for that feature. As Warren[9] points out the relative abundance of species (species richness) certainly influences our idea of diversity and should be included in an expression of diversity. However, we take the position that relative abundance expressed in terms of species per individuals collected can be so dramatically influenced by conditions of the moment (e.g., clumped sample; large hatch or spawn) as to be uninterpretable as an index to community condition. Numbers of species per unit of area/volume would seem to convey the idea of "richness" much more clearly.

Margalef[25] is credited with being the first to propose that species diversity indices be based on information theory. The most commonly used expressions are the Shannon-Wiener function:

$$H = -\sum_{i=1}^{S} \pi_i \log_2 \pi_i, \text{ in the form:}$$

$$h = -\sum_{i=1}^{S} n_i/N \log_2 n_i/N,$$

where, H = entropy, S = number of species;
and Brillouin's[26] index:

$$\bar{H} = (1/N)(\log N! - \sum_{1}^{S} \log N_i).$$

where the terms are as defined above.

If the n_i are large the two formulations give comparable results but in most cases the n_i's are not large. The information theory formulae are used to compute the uncertainty concerning the species. The degree of uncertainty is greater when the diversity is greater. Commonly authors refer to bits of information per unit. Further, a propounded advantage is that the index may be used on continuous variables such as biomass, size, or chemical content and is not limited to numbers of individuals or numbers of species.

FRESHWATER

For the investigation of freshwater streams the information theory type of index has been used more frequently than others. Some authors have reported high success in obtaining index values in terms of quality of the receiving stream water, and have, in fact, recommended that water quality criteria be drawn on specific indices. Other workers have attempted to apply recommended indices to stream situations with differing results.

Wilhm and Dorris[7,27] present data on benthic macroinvertebrates of Skeleton Creek , Oklahoma. Their data show a trend from $\bar{d} \sim 0.75$ at six miles below where municipal and industrial wastes enter the creek to a $\bar{d} \sim 3.5$ some 61 miles below the outfall. Statistical tests indicated that stations from six to 32 miles downstream from the outfall were not significantly different but that stations 43 and 61 miles downstream were significantly different from the upper stations in mean annual diversity. In the fall the three upper stations (6, 12, and 16 miles downstream) were significantly different from stations at 27 and 32 miles downstream and in spring stations at 6, 12, 16, 27, and 32 miles downstream were not significantly different from each other but were significantly different from a station 61 miles downstream. Wilhm and Dorris[7] present data from other studies in support of the usefulness of diversity as criteria (see Table 6). They summarize by, "Values less than 1 have been obtained in areas of heavy pollution, values from 1 to 3 in areas of moderate pollution and values exceeding 3 in clean water areas".

In a similar vein, Prophet and Edwards[28] examined $\bar{d}$ (diversity per individual) for macroinvertebrates in a Great Plains stream receiving feedlot runoff. Their data are presented on Table 7. From the range of values for the 1968-1969 period, they concluded that the system was experiencing moderate environmental stress. Cottonwood Falls and Soden's Grove were points receiving major feedlot runoff. Statistical analysis of individual $\bar{d}$'s detected significant (0.05) differences between $\bar{d}$'s at Elmdale and West Emporia, Kansas, (clean stations) when compared to the other three stations. Further, they concluded that $\bar{d}$'s from the second sampling period, 1970-1971, indicated recovery after the runoff was reduced.

Table 6. EXAMPLES OF SPECIES DIVERSITY, d, IN POLLUTED WATERS
(after Wilhm and Dorris, 1968)

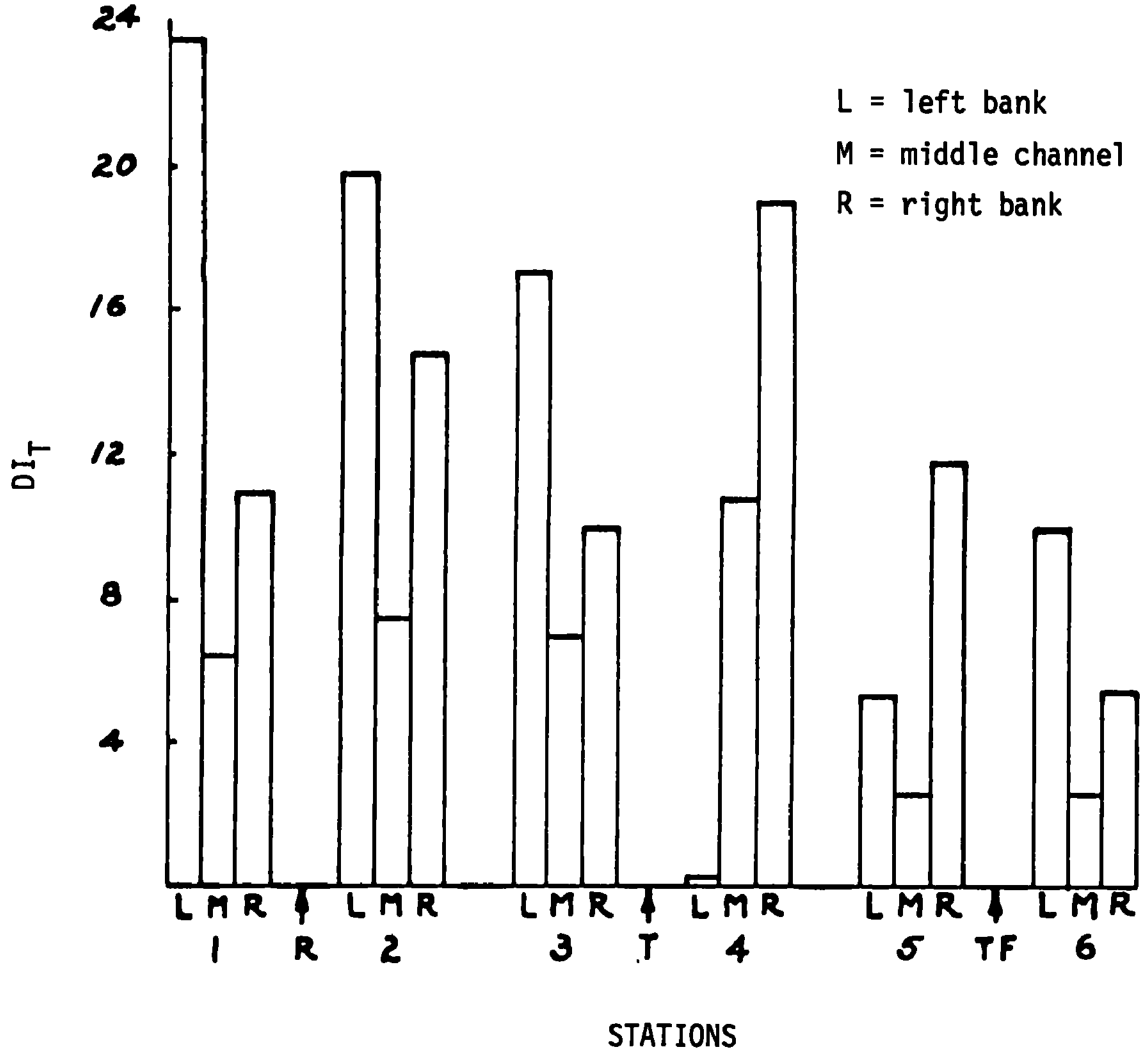
		d			
Area	Pollutants	Above outfall	Near outfall	Downstream	
Skeleton Creek	Domestic, oil refinery	*	0.84	1.59	3.44
Skeleton Creek	Domestic, oil refinery	3.75	0.94	2.43	3.80
Otter Creek	Oil field brines	3.36	1.58		3.84
Refinery ponds	Oil refinery	*	0.98	2.79	3.17
Keystone Reservoir	Dissolved solids		0.55		3.01
Alamitos Bay	Oil field brines	*	1.49	2.50	*
Alamitos Bay	Oil field brines	*	1.44	2.70	*
Alamitos Bay	Storm sewer	*	1.45	2.81	*

*Data not available.

Table 7. COMPARISON OF MEAN ANNUAL $\bar{d}$
(DIVERSITY PER INDIVIDUAL) VALUES PER STATION
(after Prophet and Edwards, 1973)

Station	Mean $\bar{d}$ 1968-1969	Mean $\bar{d}$ 1970-1971
Elmdale	2.86	2.73
Cottonwood Falls	2.05	3.09
West Emporia	2.70	3.18
Soden's Grove	2.02	2.57
Neosho Rapids	2.39	2.85

Figure 1. DI_T for six stations in the New River, Va. (R-rock crusher, T-tannery, TF=textile fiber plant.) (Modified from Cairns and Dickson, 1971.)



Some of the more recent investigators in freshwater streams have attempted to simplify the process of obtaining diversity indices so that they may be computed by persons without biological training. Perhaps the most elaborate scheme has been devised by Cairns and others[29], Cairns and Dickson[8,30] who have devised a "sequential comparison index (S.C.I.). Data are acquired from samples by sorting the individuals into groups with obvious differences in appearance. Densities for the groups are obtained by counting. A sample for a given station is randomized by gentle shaking of the collection jar and then pouring the contents into a flat white enamel pan. Only two specimens need be compared at a time. If the specimen nearest the first examined is similar to the first, then it is part of the same "run". If not, a new run is begun. If fewer than 250 individuals are in the sample, then the index will simply be the number of "runs" divided by the number of specimens. If there are greater than 250 specimens, then increments of 50 specimens are counted and an index computed as number of "runs" divided by 50. Cumulative indices are calculated in incfements of 50 until the plot of index against number of specimens becomes asymptotic. Cairns and Dickson[8,30] summarize the technique in some 19 steps which should be consulted for details. They report that healthy streams with high diversity and a balanced density seem to have DI_T values above 12.0, polluted communities with skewed population structures have given values of 8.0 or less, and that intermediate values have been found in semipolluted situations. They present a case history to illustrate the usefulness of the index. Data presented on Figure 1 are from Cairns and Dickson[8].

A second approach toward simplification has been taken by Egloff and Brakel[31]. They computed Patten's[18] index:

$$\bar{d} = \Sigma\ N_i/N \log_2 N_i/N,$$

where N = the total number of individuals and N_i = the number of individuals in the ith species. However, they substitute higher taxa for numbers of species. Thus genera, orders, and classes are used in place of specific identifications. Further, they compute an evenness component, from Pielou[11]: $e = \bar{d}/\log_2 S$. Data are presented graphically on the indices computed at the generic level for comparison of samples collected with Surber and Ekman samplers at stations above and below a wastewater outfall. Sharp declines in $\bar{d}$ calculated for the total samples and for the Surber samples are evident from a station above the outfall and one immediately below. A similar trend is apparent for numbers of species, S, and evenness, e. Significant (0.01) correlations were found between $\bar{d}$ and BOD, PO_4, and NO_3. Significant correlations to the same water quality components were detected for numbers of species, S.

Archibald[32] compares data calculated for several common indices of species diversity relating to South African stream diatom associations. The indices compared are:

1. Simpson's index - $S.I. = \sum_{i=1}^{m} \pi_i^2$ (Duffy[33]),

where π_i is the proportion in the ith species in sample.

2. Menhinick's index - $S/\sqrt{N}$ (Wilhm[34]),

where S is the number of species and N = total number of individuals.

3. Margalef's index - $S-1/\log_e N$ (Wilhm[34]),

where S and N are as above.

4. Brillouin's index - $\bar{H} = K (\log N! - \sum_{i=1}^{m} \log n_i!/N$,

where K , the conversion factor $\log_{10}$ to $\log_2$ is 3.322, N = total number of individuals in the sample, n_i = number of individuals of the ith species.

5. Patten's redundancy - $R = H_{max}-H/H_{max}-H_{min}$,

where $H = K (\log N! - \sum_{i=1}^{m} \log n_i!)$, and $H_{min} = K \{\log N! - [\log N-(S-1)]!\}$, where S = number of species in sample; N and n_i are as above.

6. Cairn's sequential comparison index from:

"runs"/200 where 200 specimens were used in each case.

Resulting data are presented on Table 8. Table 9 is a listing of the correlation coefficients.

From the correlation data, Archibald[32] concludes that all pairs of indices have significant correlation (P = 99.9 percent), and thus selection of an index for use should be based on three considerations, i.e., (1) time required to sort the sample; (2) ease of index calculation; and (3) the characteristic of fixed limits. Archibald concluded the S.C.I. best met each of the criteria.

Table 8. SPECIES DIVERSITY VALUES FOR THE SAMPLES UNDER OBSERVATION AS OBTAINED FROM DIFFERENT DIVERSITY INDICES (after Archibald, 1972)

			Diversity indices					
Sample number	s	N	S.I.	s/ N	s - 1/lnN	$\bar{H}$	R	S.C.I.
306	11	441	0.82	0.524	1.64	0.638	0.862	0.320
315	38	399	0.08	1.903	6.18	4.023	0.196	0.840
324	41	394	0.10	2.065	6.69	3.777	0.283	0.885
338	20	382	0.16	1.024	3.20	3.026	0.307	0.780
339	41	410	0.07	2.025	6.65	4.135	0.221	0.885
340	30	372	0.12	1.555	4.90	3.526	0.305	0.845
342	39	366	0.09	2.039	6.44	3.872	0.294	0.910
344	43	386	0.10	2.188	7.05	3.822	0.307	0.905
350	23	462	0.54	1.070	3.59	1.715	0.673	0.615
353	32	399	0.27	1.602	5.18	2.928	0.466	0.855
375	14	375	0.33	0.728	2.19	1.950	0.506	0.700
377	12	364	0.79	0.629	1.87	0.749	0.849	0.435
406	28	387	0.28	1.423	4.53	2.348	0.557	0.665
464	16	388	0.58	0.869	2.52	1.457	0.690	0.550
493	22	392	0.41	1.111	3.52	2.106	0.565	0.800
495	27	423	0.23	1.313	4.30	2.688	0.447	0.725
497	14	450	0.70	0.660	2.13	1.087	0.760	0.235
498	17	396	0.20	0.854	2.67	2.717	0.352	0.690
K22	15	442	0.74	0.715	2.30	0.959	0.810	0.165

Table 9. CORRELATION COEFFICIENTS OF DIFFERENT PAIRS OF DIVERSITY INDICES[a] (after Archibald, 1972)

	R	$\bar{H}$	$S - 1/\log_e N$	$S/\sqrt{N}$	S.I.
S.C.I.	-0.89	+0.90	+0.80	+0.81	-0.92
S.I.	+0.98	-0.97	-0.82	-0.89	
$S/\sqrt{N}$	-0.81	+0.91	+0.99		
$S - 1/\log_e N$	-0.76	-0.81			
$\bar{H}$	-0.98				

[a]With 17 degrees of freedom $p \geqslant 99.9$ per cent (sic) when $\underline{r} \geqslant 0.6932$ (Fisher and Yates (1948)-Statistical Tables for Biological and Medical Research. Oliver & Boyd, Edinburgh, Table VI).

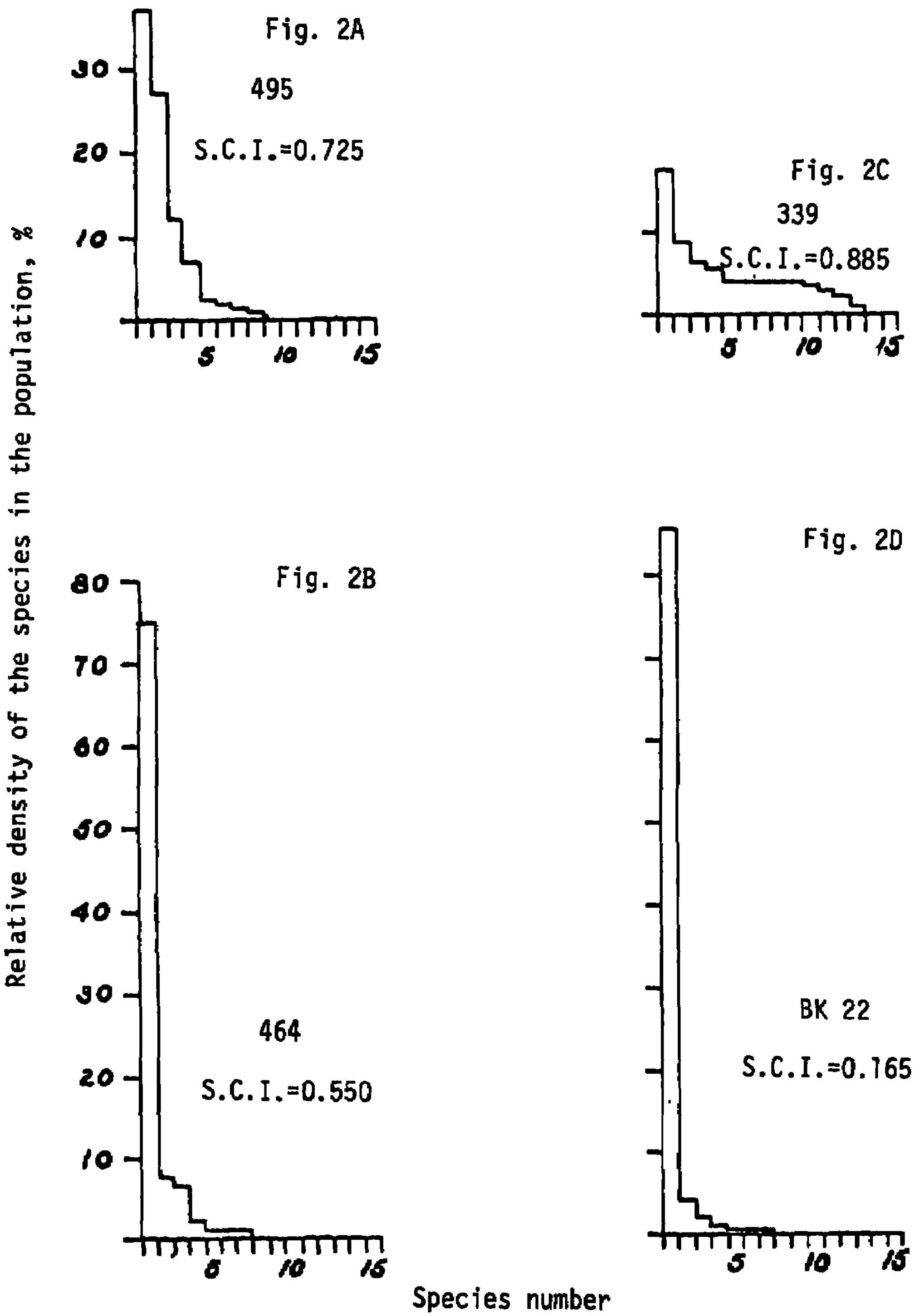
Archibald applied S.C.I. to diatom associations with an interesting and informative result. The data, presented in graphical form, Figure 2 (A through D) show differing values for the index but not in relation to the "polluted" nature of the areas from which the collections were made. Thus, Figure 2A represents a "clean" water association with a S.C.I. value of 0.725; Figure 2C is from a moderately stressed region having a slightly higher S.C.I. value, 0.885. Figure 2C is an association from "clean" water which is dominated by a single species with an S.C.I. value of 0.550 while Figure 2D is an association from a heavily polluted region having an S.C.I. value of 0.165. Archibald recognizes that the diatom associations may be quite different from the macroinvertebrate "communities" for which good correlations between index values and pollution have been found. He does, however, point out that the results of his study serve to illustrate the need for caution in interpretation of raw index values in pollution studies.

Further support for the use of such caution in the use of the information index alone comes from Lotrich[35] who used H to detect the effects of strip mine wastes on stream fishes. He determined that abundance of the fishes was reduced by about one-half but that since the reduction was somewhat equally distributed among the species an effect ws not elucidated by the index. Dickman[36] in working with algae, found that an index based on productivity was more useful than the Shannon information index. Whiteside and McNatt[37] obtained a positive correlation of the information index for stream fishes to stream order. Inexplicably, however, the relationship did not hold for the highest stream order. The authors attributed the exception to sampling inefficiency.

McKay and Kalft[38] used a species richness type index, $d = S\text{-}1/\log_e N$, to evaluate small stream benthos. They determined statistically significant differences in seasonal values with higher values for the index in winter and in summer than for fall and spring.

Several authors have conducted experimental studies in laboratory streams using the Shannon information index. Mitchell[39] used freshwater algae in an experimental situation. He relied on the index to determine the effects of the addition of aliquots of wastewater and detergents and concluded from index values that the contaminants produced no change. In experimental

Figure 2. Structure of diatom communities (modified from Archibald, 1972)



streams, Ewing and Dorris[40] found an increasing value for the information index, $\overline{H}$ through time, but found no significant correlation to the P/R ratio. Likewise Kehde[41] determined increasing diversity values through time in laboratory streams but did not detect a difference in diversity for grazed versus ungrazed periphyton. Patrick[42] obtained similar values (about 3.2) for the Shannon index in freshwater stream replicates of similar character.

TERRESTRIAL

Unlike the situation in freshwater, investigators in the terrestrial habitat have emphasized the use of diversity indices to describe the effects of natural variables, i.e., food density, precipitation, cover, predation. Further, in the terrestrial habitat there has been a much greater distinction between the components of diversity than was the case for many freshwater studies. There has been much less tendency to ascribe specific levels for a particular index in the terrestrial habitat. There is an apparent increase in diversity with community succession.

Information theory type indices have been used most frequently. The discussion of bird species diversity in terms of foliage has received attention. MacArthur and MacArthur[43] proposed niche description for birds in terms of the diversity index, BSD = $-\Sigma p_i \log P_i$. MacArthur[44] found that BSD related positively to foliage height diversity within habitats but not across habitats. Further, he pointed out that 20 to 25 pairs of birds were needed for comparison and that sampling schemes based on a specific area might not provide an adequate sample. Karr[45] examined the distribution of Shannon's H with respect to birds in lowland tropical grass, shrub, and forest habitats. Diversity, as indicated by the index, was higher for shrubs than grass or forest and was relatively stable seasonally. Kricher[46] used an information H' and the J' component of Pielou[11] for evenness of distribution. He determined a low and variable value to be characteristic of early successional stages or ecosystems characterized by opportunistic species. The information index, H', more nearly correlated to number of species than did the evenness component. J' distinguished nesting and territorality since it was stable from census to census. In a later paper Kricher[47] gave some time values for development of diversity. Thus, he states that bird species diversity on a developing sere increases with time to about 150 years.

The BSD-time curve flattens somewhat after about 30 years. Wiens[48] used the information index and the equitability component of Lloyd and Ghelardi[49] for birds in forests. He found that the values were uniformly low and that neither index gave a consistent pattern with habitat heterogeneity.

Turning to other species in the terrestrial habitat, Luff[50] found the equitability index of Lloyd and Ghelardi[49] to be useful in describing the distribution of the beetle fauna of grass tussocks. He limited interpretive remarks to a discussion of his own data. Monk and others[51] observed a positive relationship between MacArthur's index, $-\Sigma\ p_i \log_e P_i$, and sample size in an oak-hickory forest. Fleming[52] used the information index, H', to describe the world distribution of terrestrial mammals. He determined a southward increase in numbers of species. Heyer and Berren[53] described the distribution of frogs, lizards, and snails of tree buttresses in Thailand and Equador. A higher diversity was found in Equador. To illustrate the versatility of the information index, Hurtubia[54] compared the food of lizards to lizard diversity. Brown[55] found the information index to be well correlated to predictable annual rainfall when applied to sand dune rodents. Coulson[56] compared beetle diversity in monocultures of white pine to that in mixed coppice stands and determined higher diversity in the mixed stands. Murdock and others[57] used the Brillouin information index and obtained a good correlation between insect diversity and plant diversity. They observed a consistent midsummer dip in index values. Randolph[58] obtained values of 0.76 in Johnson grass to 1.57 in woods for the Shannon index. He concluded that the relative abundance component was more influential than numbers of species. Pianka[5] used the information index, H, in comparing lizards of North American deserts. He concluded that ecological time would be important in determining diversity only when there were pronounced barriers to dispersal. He further concluded that numbers of species, as an indicator, would only be useful as a long-term parameter, i.e., greater than five years. Shafi and Yarranton[59] studied the effects of fire on the succession of a forest. In concluding remarks they state, "The weakness of diversity as an ecological tool lies in its ambiguity". They further point out that one must always consider at least two components. The long-term successional trend was in the direction of declining diversity values. They attributed high values and fluctuations during four to eleven years after burnings to the effects of species richness rather than evenness.

In an experimental study of terrestrial grasslands, Malone[60] used the species richness formula, $\underline{d} = S-1/\log_e N$, to detect the effects of an arsenical herbicide. He found that $\underline{d}$ declined in proportion to the amount of chemical added.

MARINE

In the marine environment, diversity indices used have mostly been those based on information theory although there has been a considerable impact in the literature based on Sanders[19] rarefaction techniques for determining the effects of differing sample sizes. Information type indices were used by Jackson[61], Abele[62], Boesch[63], Cameron[64], Cooper and Copeland[65], Coull[66], Dahlberg and Odum[67], Johnson and Brinkhurst[68], Johnson[69,70], Kohn[71], Lie and Kisker[72], Lie and Evans[73], Patten[74], and Porter[75,76].

Investigators of the marine environment who have used the information index have been predominantly concerned with the marine benthos. Abele[62] computed the information index, H', and the evenness component, J', (Lloyd and Ghelardi[49]) for marine decapods. He found good correlation of H' and sediment type but did not find a significant correlation of the index to temperature or tidal exposure. Jackson[61] compared animal diversity on Thallassia beds in the intertidal zone of a bay and exposed coast. He found a greater diversity, as revealed by Brillouin's[26] index in the bay habitat. Johnson[69] determined an increasing value of H (Brillouin) from high intertidal to subtidal. He introduced a ranking system based on the order of appearance in succession to a stress gradient. In a later paper Johnson[70] states that polychaete and mollusk communities are sensitive to environmental change. Lie and Kisker[72] determined increasing diversity with an information index from shallower to deeper subtidal waters applied to the benthos. They postulated that the trend was related to greater environmental stability. Lie and Evans[73] discussed the variability in the information index under natural or baseline conditions. Coull[66] used several indices to compare marine microbenthos and concluded that the Shannon information index agreed well with Sanders[19] rarefaction techniques and that the indices indicated that diversity increased with depth and environmental stability. Boesch[63] compared the Shannon information index and others for analysis of estuarine benthos and concluded that only if several indices were used concurrently, useful information could be obtained.

Information theory indices have also been applied to estuarine fish, plankton, marine corals, and salt marshes. Dahlberg and Odum[67] applied several indices to estuarine fish and concluded, "In terms of practical application of diversity indices to detection and evaluation of pollution, it would appear that indices $\bar{H}$ and D are seasonally stable and, therefore, suitable general indices that could be applied to any season". Further on they conclude, "It is evident that a combination of indices which reflect the different components of diversity should be selected and that these should be based on the seasonal and sample characteristics of populations to be monitored". Patten[74] developed a diversity index, $D = \sum_{i=1}^{m} X_i \log_2 (X_i/X)$, to describe diversity of marine plankton. He found that diversity dropped off abruptly at compensation depth. Maximum diversity occurred at 60 cm depth and Patten related his index to system energy. Cooper and Copeland[65] constructed a model of Galveston Bay to which they applied an information theory index for zooplankton. They determined a positive correlation between index value and system development time and a reduced index value in response to 15 percent industrial effluent.

Cameron[64] studied the relationship of the Brillouin information index to physical and chemical variables in a salt marsh. He states, "Physical microenvironmental factors, especially temperature and vapor pressure deficit, seemed to be important in cuing larval development, but did not exert a dramatic effect on adult diversity trends". His study included multivariate analysis and although significant microenvironmental effects on the index were determined, the analysis did not detect spraying with insecticide as a significant effect on insect diversity.

Porter[75,76] studied marine corals in terms of an information theory index. He concluded that a high concentration of predators produced a higher diversity in coral and attributed the higher diversity to the evenness component. He states, "...best single indicator of species diversity is S". (Number of species.)

At least two authors have used species richness type indicators for marine plankton analysis. Ignatiades[77] used the formula, $D = 1/N \log_2 N!/N_{a!}$, for pelagic plankton and concluded, "Diversity can never be computed on a total community". He further indicates, d declines with "blooms" and increases with a decline in "blooms". Hardy[78] used a species richness index and determined that the index fluctuated with season giving high values in summer and low values in winter. Further, Hardy reports that high productivity gave low diversity.

In an effort to compare effects of sample size, Sanders[19] developed a technique for estimating diversity from different sizes of samples and comparing the estimates. He discusses the necessity of comparing only for comparable habitats, in his case soft mud substrates from different parts of the world. He concluded that the Shannon-Wiener function (information index) was relatively free from sample size problems. Sanders reported an increase in diversity with increasing depth, as determined by rarefaction. Gage[79], Dexter[80], and Day[81] have used the rarefaction methodology (graphical) in similar marine benthic situations and have obtained predictable results. Simberloft[82] pointed out that the rarefaction technique overestimates the number of species.

COMPARATIVE INDEX STUDIES

Several authors have conducted studies particularly for the purpose of comparing various species diversity indices. As pointed out in the section on freshwater, Archibald[32] compared a number of common indices, determined a high correlation between indices, and concluded an index from those tested should be chosen based on ease of application. He suggested Cairns and others[29] sequential comparison index. Cairns and Dickson[8] suggested the use of the sequential comparison index for untrained persons but recommended that work continue on the information theory derived indices. Eberhardt[22] considered indices and concluded that any one of several mathematical distributions were adequate but that sampling data had not been emphasized. Further, he concluded that the various indices could serve as a convenient method of summarization but not as predictive tools. Loya[83] compared species counts, Simpson's index, and several information theory-derived indices and pointed out that while the diversity of hematypic corals increased with depth as measured by the several indices, there was a great need for the use of multiple indices. Mills[84] stated that we "...cannot define community rigorously...," it is "...an ecological unit of any degree".

He concluded that it was much too early to use diversity indices as a quantitative tool. Turner and Broadhead[85] used Fisher's index, McIntosh's index, and Brillouin's index for microepiphytes of the bark surface and obtained similar results with each of them. DeBenedictis[86] in a study considering species richness indices and information theory derived indices with evenness components, concluded that the correlations obtained were correlations of mathematics only. He stated that a relationship between any of the indices and a biological phenomenon was lacking. Hill[10] presents a unified notation which claims to interrelate several of the more common indices of species diversity as a continuum. Hurlbert[13] says that species diversity is a non-concept in ecology.

SECTION VI

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APPENDIX A

LETTER OF INQUIRY USED TO DETERMINE UNDERSTANDING OF COMMUNITIES

COMMUNITY PARAMETERS FOR ENVIRONMENTAL ASSESSMENT

Battelle-Northwest, in conducting a study for the U.S. Environmental Protection Agency, is attempting to ascertain if biological community dynamics common to the marine, freshwater, and terrestrial habitats are useful in the assessment of environmental change. As a part of these studies, we are seeking an opinion from the industrial sector, from regulatory agencies, and from researchers representing the relevant technical expertise. The following questions are designed to develop information regarding the understanding and acceptance of community response as a measure of environmental change. Please return completed inquiries in the postage paid envelopes provided. Replies should be anonymous.

SECTION I — IDENTIFICATION OF RESPONDENT

1. Of the three categories mentioned above, I am most nearly associated with:
   - ☐ Industry ☐ Regulatory agency ☐ Research
2. With respect to interest in environmental change, my main involvement is with the (one or more):
   - ☐ Terrestrial ☐ Freshwater ☐ Marine
3. My participation in environmental studies has been:
   - ☐ None ☐ Occasional ☐ Frequent ☐ Full time
4. My understanding of biological communities is:
   - ☐ Limited ☐ Moderate ☐ Comprehensive
5. Position ______________________________

   Years of experience in environmental assessment ____________________

SECTION II — TYPE OF INVOLVEMENT

1. My participation in environmental studies has principally been with:
   - ☐ Chemical criteria ☐ Laboratory toxicity studies ☐ Field surveys
   - ☐ Other (specify)
2. I have had occasion to deal with community parameters or indices of species diversity for environmental assessment:
   - ☐ Never ☐ Occasionally ☐ Frequently
3. Please indicate the habitat for which you have applied the following indices:

		Terrestrial	Freshwater	Marine
Margalef	$\overline{d} = (S-1)/\log_e N$	☐	☐	☐
Brillouin	$\overline{H} = (1/N)(\log N! - \sum_{1}^{s} \log N_i!)$	☐	☐	☐
Wilhm and Dorris modification of Brillouin	$\overline{d} = \Sigma(n_i/n)\log_2(n_i/n)$	☐	☐	☐
Patrick	Aquatic community indices of pollution	☐	☐	☐
Wurtz	Modification of Patrick method (tolerance)	☐	☐	☐

SECTION II — TYPE OF INVOLVEMENT (CONTINUED)

		Terrestrial	Freshwater	Marine
Fisher	$\alpha x + \alpha x\ 2/2 = \alpha x\ 3/3 + \ldots + \alpha x\ h/h$	☐	☐	☐
Simpson	$N^2/\Sigma n(n-1)$	☐	☐	☐
Mountford	$I = 2ab \overset{2j}{\sim} (a+b)_j$	☐	☐	☐
Lloyd, Zar, and Kar	$\bar{d} = C/N\ (N \log_{10} N - ni \log_{10} ni)$	☐	☐	☐
Beck	Biotic index = 2(n Class I) + (Class II)	☐	☐	☐
Aerial Surveys		☐	☐	☐
Experimental plots (quadrats)		☐	☐	☐
Other (please specify)		☐	☐	☐

4. Comments:

SECTION III — OPINION

1. In your opinion, an indicator of environmental change should be mainly:
   - ☐ Chemical analyses ☐ The organism ☐ The population
   - ☐ The community ☐ Combination of above (please specify)
   - ☐ No opinion ☐ Other (please specify)

2. Is there a parameter of community response (index) indicative of environmental change?
   - ☐ None ☐ One ☐ More than one ☐ No opinion

3. Would you recommend any of the indices listed in Section II for general use by personnel with limited training?
   - ☐ No ☐ Yes (which one(s))

4. Are there other indices or methods you have used to measure environmental change?
   - ☐ No ☐ Yes (please specify)

Comments

5. In general, how do you rate the usefulness of community analysis?
   - ☐ Poor ☐ Fair ☐ Good ☐ Excellent

   Would you participate in a personal interview with one of our investigators?
   - ☐ Yes (please send telephone number or call collect, 206/683-4151)
   - ☐ No

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APPENDIX B

DATA SUMMARY OF WRITTEN INQUIRIES BY ASSOCIATIVE GROUP

Section I. Identification of respondent

Question	Industry		Regulatory Agency		Research	
	Number	Percent	Number	Percent	Number	Percent
2. HABITAT						
Terrestrial	7	24	7	8	114	51
Freshwater	10	34	56	67	67	30
Marine	5	17	7	8	18	8
Unidentified	7	25	13	17	23	11
Total	29	100	83	100	222	100
3. PARTICIPATION						
None	1	3	4	5	3	1
Occasionally	7	24	15	18	55	25
Frequently	9	31	31	37	95	43
Full time	12	42	32	39	63	28
Inconclusive	0	0	1	1	6	3
Total	29	100	83	100	222	100
4. UNDERSTANDING						
Limited	8	28	4	5	10	5
Moderate	13	45	31	37	80	36
Comprehensive	7	24	44	53	132	59
Inconclusive	1	3	4	5	0	0
Total	29	100	83	100	222	100
5.a. POSITION						
Biologist-ecologist	9	31	35	42	151	68
Chemist	1	3	2	2	1	0
Engineer	1	3	14	17	1	0
Enforcement officer	0	0	4	5	0	0
Other	17	59	27	33	10	5
Unidentified	1	4	1	1	59	27
Total	29	100	83	100	222	100

Question	Industry Number	Industry Percent	Regulatory agency Number	Regulatory agency Percent	Research Number	Research Percent
5.b. EXPERIENCE (years)[1]						
0 - 2	2	7	8	10	10	5
2 - 5	6	21	23	28	42	19
5 - 10	8	27	23	28	47	21
10+	13	45	29	34	116	52
Inconclusive	0	0	0	0	7	3
Total	29	100	83	100	222	100
Section II. Type of involvement						
1. CRITERIA USED						
Chemical	5	17	10	12	3	1
Laboratory toxicity	1	3	2	2	6	3
Field survey	9	31	43	52	130	59
Other	8	28	2	2	16	7
Inconclusive	6	21	26	32	67	30
Total	29	100	83	100	222	100
2. PARTICIPATION						
Never	10	34	10	12	26	12
Occasionally	13	46	45	54	113	51
Frequently	5	17	23	28	79	35
Inconclusive	1	3	5	6	4	2
Total	29	100	83	100	222	100
3. INDICES USED						
Terrestrial	13		17		133	
Freshwater	11		59		96	
Marine	6		45		34	
Total	19		70		199	
Percent respondents using index on one or more habitats		66		84		90

[1]Responses falling on a division were elevated to the next higher rank.

APPENDIX B (continued)

Section III. Opinion

Question	Industry Number	Industry Percent	Regulatory agency Number	Regulatory agency Percent	Research Number	Research Percent
1. INDICATOR						
Chemical	12	41	28	34	62	28
Organism	9	31	28	34	75	34
Population	12	41	26	31	116	52
Community	16	55	56	67	156	71
Combination	13	45	51	61	134	61
No opinion	2	7	3	4	3	1
Other	4	14	1	1	13	6
Inconclusive	0	0	1	1	4	2
Total	68		194		563	
Mean number indicators/respondent		2.3		2.3		2.5
2. NUMBER OF PARAMETERS						
None	3	10	2	2	10	5
One	1	4	0	0	2	1
More than one	13	45	52	63	171	77
No opinion	11	38	15	18	17	8
Inconclusive	1	3	14	17	21	9
Total	29	100	83	100	22	100
3. LIMITED TRAINING						
No	17	59	51	61	120	55
Yes	2	7	18	22	63	28
Inconclusive	10	34	14	17	38	17
Total	29	100	83	100	221	100
4. OTHER INDICES						
No	9	31	31	37	75	34
Yes	11	38	35	42	103	47
Inconclusive	9	31	17	21	43	19
Total	29	100	83	100	221	100

Question	Industry		Regulatory agency		Research	
	Number	Percent	Number	Percent	Number	Percent
5. RATING						
Poor	5	17	4	5	3	1
Fair	4	14	19	23	42	19
Good	10	34	30	36	83	38
Excellent	3	10	15	18	57	26
Inconclusive	7	25	15	18	36	16
Total	29	100	83	100	221	100

APPENDIX C

DATA SUMMARY OF WRITTEN INQUIRIRES BY PRINCIPAL HABITAT

Section II. Type of involvement

Question	Terrestrial		Freshwater		Marine		Undecided	
	Number	Percent	Number	Percent	Number	Percent	Number	Percent
1. CRITERIA USED								
Chemical	2	2	11	8	0	0	3	7
Laboratory toxicity	2	2	3	2	2	7	2	5
Field survey	94	73	55	42	18	62	19	42
Other	11	8	4	3	2	7	6	13
Inconclusive	19	15	58	45	7	24	15	33
Total	128	100	131	100	29	100	45	100
2. PARTICIPATION								
Never	13	10	13	10	2	7	16	35
Occasionally	75	59	68	52	13	45	14	31
Frequently	36	28	45	34	14	48	12	27
Inconclusive	4	3	5	4	0	0	3	7
Total	128	100	131	100	29	100	45	100
3. INDICES USED								
Terrestrial	120		18		3		23	
Freshwater	19		114		7		25	
Marine	0		21		27		11	
Total	120		117		27		26	
Percent respondents using index on one or more habitats		94		89		93		58

APPENDIX C (continued)

Section III. Opinion

Question	Terrestrial		Freshwater		Marine		Undecided	
	Number	Percent	Number	Percent	Number	Percent	Number	Percent
1. INDICATOR								
Chemical	33	26	47	36	12	41	17	38
Organism	50	39	46	35	8	28	15	33
Population	74	58	49	37	14	48	20	44
Community	96	75	96	73	19	66	23	51
Combination	80	63	82	63	23	79	26	58
No opinion	2	2	1	1	1	3	5	11
Other	7	5	0	0	2	6	4	9
Inconclusive	1	1	4	3	0	0	1	2
Total	343		325		79		111	
Mean number of indicators/respondent		2.7		2.5		2.7		2.5
2. NUMBER OF PARAMETERS								
None	7	5	5	4	0	0	3	7
One	1	1	2	1	0	0	0	0
More than one	90	70	97	74	21	72	28	63
No opinion	16	13	18	14	2	7	7	15
Inconclusive	14	11	9	7	6	21	7	15
Total	128	100	131	100	29	100	45	100

APPENDIX C (continued)

	Question	Terrestrial		Freshwater		Marine		Undecided	
		Number	Percent	Number	Percent	Number	Percent	Number	Percent
3.	LIMITED TRAINING								
	No	64	50	75	57	19	65	27	60
	Yes	38	31	37	28	6	21	7	16
	Inconclusive	25	19	19	15	4	14	11	24
	Total	127	100	131	100	29	100	45	100
4.	OTHER INDICES								
	No	49	38	51	39	6	21	11	24
	Yes	51	40	58	44	18	62	20	45
	Inconclusive	28	22	22	17	5	17	14	31
	Total	128	100	131	100	29	100	45	100
5.	RATING								
	Poor	2	1	6	4	2	7	3	7
	Fair	22	17	30	23	3	10	9	20
	Good	51	40	54	41	10	34	11	24
	Excellent	34	27	27	21	8	28	5	11
	Inconclusive	19	15	14	11	6	21	17	38
	Total	128	100	131	100	29	100	45	100

APPENDIX D

DATA SUMMARY OF WRITTEN INQUIRIES BY YEARS OF EXPERIENCE[1]

Section II. Type of involvement

Question	0 - 2		2 - 5		5 - 10		10+		Undecided	
	Number	Percent	Number	Percent	Number	Percent	Number	Percent	Number	Percent
1. CRITERIA USED										
Chemical	2	10	3	4	5	7	4	2	0	0
Laboratory toxicity	1	5	5	7	1	1	1	1	1	17
Field survey	8	40	39	55	42	54	89	56	1	17
Other	4	20	5	7	4	5	10	6	1	17
Inconclusive	5	25	19	27	26	33	55	35	3	49
Total	20	100	71	100	78	100	159	100	6	100
2. PARTICIPATION										
Never	6	30	12	17	7	9	9	6	1	17
Occasionally	8	40	33	47	47	60	80	50	3	49
Frequently	2	10	23	32	23	30	57	36	1	17
Inconclusive	4	20	3	4	1	1	13	8	1	17
Total	20	100	71	100	78	100	159	100	6	100
3. INDICES USED										
Terrestrial	7		30		32		94		2	
Freshwater	8		31		45		80		0	
Marine	13		30		16		28		0	
Total	13		38		69		146		2	
Percent respondents using index on one or more habitats		65		54		88		92		33

[1]Responses falling on a division were elevated to the next higher rank.

APPENDIX D (continued)

Section III. Opinion

Question	0 - 2 Number	0 - 2 Percent	2 - 5 Number	2 - 5 Percent	5 - 10 Number	5 - 10 Percent	10+ Number	10+ Percent	Undecided Number	Undecided Percent
1. INDICATOR										
Chemical	11	55	19	27	28	36	46	29	4	67
Organism	10	50	15	21	27	35	60	38	5	83
Population	12	60	21	30	37	47	83	52	5	83
Community	15	75	48	68	51	65	112	70	5	83
Combination	15	75	31	44	48	62	114	72	5	83
No opinion	3	15	1	1	4	5	0	0	0	0
Other	0	0	5	7	1	1	6	4	0	0
Inconclusive	0	0	5	7	3	4	3	2	0	0
Total	66		145		199		424		24	
Mean number of indicators/respondent		3.3		2.0		2.5		2.7		4.0
2. NUMBER OF PARAMETERS										
None	0	0	3	4	3	4	8	5	1	17
One	0	0	0	0	1	1	2	1	0	0
More than one	10	50	53	75	49	63	121	76	4	66
No opinion	8	40	11	15	13	17	13	8	0	0
Inconclusive	2	10	4	6	12	15	15	10	1	17
Total	20	100	71	100	78	100	159	100	6	100
3. LIMITED TRAINING										
No	9	45	39	55	42	54	92	58	3	50
Yes	4	20	17	24	24	31	43	27	1	17
Inconclusive	7	35	15	21	12	15	24	15	2	33
Total	20	100	71	100	78	100	159	100	6	100

APPENDIX D (continued)

Question	0 - 2		2 - 5		5 - 10		10+		Undecided	
	Number	Percent	Number	Percent	Number	Percent	Number	Percent	Number	Percent
4. OTHER INDICES										
No	14	70	28	40	21	27	51	32	2	33
Yes	3	15	32	45	36	46	78	49	1	17
Inconclusive	3	15	11	15	21	27	30	19	3	50
Total	20	100	71	100	78	100	159	100	6	100
5. RATING										
Poor	0	0	2	2	4	5	6	4	0	0
Fair	3	15	12	17	15	19	37	23	0	0
Good	5	25	31	44	28	36	61	38	4	67
Excellent	4	20	19	27	17	22	33	21	0	0
Inconclusive	8	40	7	10	14	18	22	14	2	33
Total	20	100	71	100	78	100	159	100	6	100