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BIOLOGICAL SURVEILLANCE OF CHALK-STREAMS

L. C. V. PINDER

Introduction

Indices based on macroinvertebrate communities have been used for surveillance of the quality of river water for many years (e.g. Woodiwiss 1964; Chandler 1970). Two types of index are commonly used. Quantitative indices, which are a measure of faunal diversity, take account of the distribution of individuals among the represented taxa (e.g. Wilhm 1970) whereas qualitative indices, or biotic scores, weight taxa according to their known, or assumed, levels of tolerance to organic pollution (e.g. Chandler 1970). The latter have usually been developed in relation to particular rivers or areas, but have often been applied subsequently to a variety of situations for which they were not intended (Armitage et al. 1983). In 1981, the National Water Council published details of the 'Biological Monitoring Working Party Score' (BMWP or NWC Score) which was used in the 1980 survey of rivers in England and Wales. This index was designed to be widely applicable and acceptable in Britain. Its performance has been assessed by Chesters (1980) and by Armitage et al. (1983).

Chalk-streams

The chalk-streams of southern England are, in general, free from serious problems of pollution and are valuable as game-fisheries (Ladle & Casey 1979). However, they are being used to an increasing extent for a variety of other purposes, including domestic water supply, fish-farming, growing of water-cress and the disposal of sewage and agricultural effluents.

Wessex Water have noted a decline in water quality in the headwaters of such streams (National Water Council 1981; Department of the Environment 1987) which is partly attributable to agricultural effluents. Casey & Clark (1970) reported a progressive increase in nitrate levels in the River Frome (Dorset) resulting from the increased use of inorganic, agricultural fertilizers.

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In view of such increasing pressures, and the value of chalk-streams as trout and salmon fisheries it is desirable that techniques should be available for the detection of perturbations to the ecosystem at an early stage and that base-line information should be available for the objective interpretation of data derived from surveillance programmes.

As a result of such considerations a research programme, jointly funded by the Department of the Environment and the Natural Environment Research Council, was initiated at the River Laboratory in 1977, with the following objectives:

"To evaluate some sampling procedures and methods of data analysis and to relate biological and chemical changes in the River Frome to human activities within the catchment with a view to recommending suitable techniques for surveillance of rivers of this type".

The results were submitted as a report to the Department of the Environment and have largely been published as a series of papers (Casey & Farr 1982; Pinder 1980; Pinder et al. 1987; Pinder & Farr 1987a; Pinder & Farr 1987b).

The River Frome

According to Paolillo (1969) chalk outcrops over almost 50% of the catchment of the River Frome (Fig. 1), although for much of its length it flows

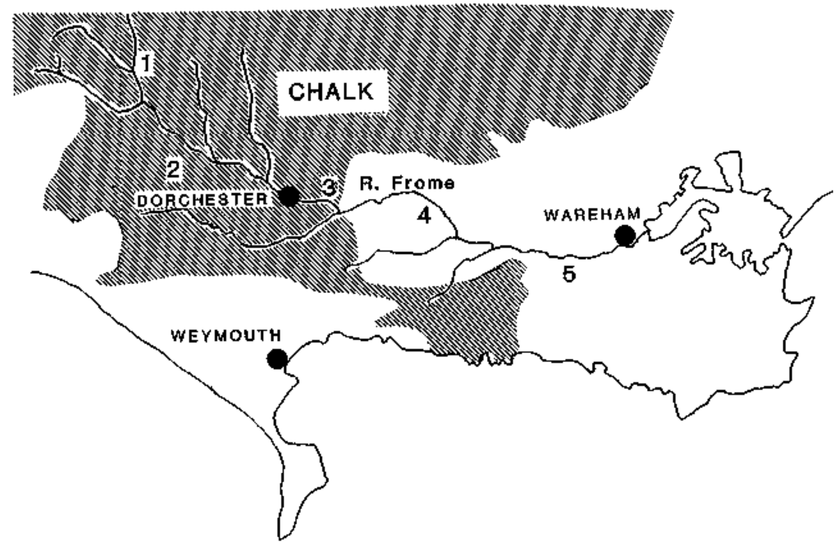

FIG. 1. The River Frome catchment, showing approximate positions of the five principal sampling sites.

over tertiary sand and gravel deposits. The Frome valley is a mainly agricultural region; primarily dairying and cereal growing, although there are some small forested areas and patches of heathland. Fish-farms are located at the head of two major tributaries, the River Hooke and the Sydling Brook, while the source of a third, the Tadnoll Brook, is the site of a water-cress farm. The only major sewage works are associated with the county town of Dorchester although the headwaters in particular are affected by a variety of small effluents. The chemistry of the Frome has been described by Casey & Newton (1973).

Evaluation of surveillance methods in chalk-streams

Sampling methods

Chalk-streams present a great variety of habitats. Typically, patches of gravel are interspersed with dense beds of emergent and submerged macrophytes which greatly modify flow patterns, creating fast runs and slack areas within which fine sediments, sand and silt, accumulate.

The practice usually adopted for surveillance using invertebrates is to attempt to sample all available habitats using a pond net, either by sweeping' or by 'kick-sampling'. Pinder et al. (1987) sampled the dominant macrophyte (*Ranunculus penicillatus* var. *calcareus* (R. W. Butcher) C. D. K. Cook), gravel and soft sediments in the River Frome, separately, in May and again in September. Gravel and soft sediments were sampled using a coring device and *R. calcareus* was sampled by manually removing the vegetation enclosed within a 25 cm quadrat. Fifteen replicate samples were taken in each case.

The density of invertebrates on *R. calcareus* was extremely high (>400,000 m^{-2} in May and *c.* 75,000 m^{-2} in September), but this fauna was dominated by a few species of Simuliidae which had the effect of depressing the values of diversity indices (e.g. Fig. 2). Samples of soft sediment taken in September were also dominated by few species, in this case of Oligochaeta, with a similar depressing effect on diversity. In contrast, gravel samples have a relatively even distribution of individuals among taxa and a correspondingly higher diversity (Fig. 2).

Furthermore gravel samples included a higher proportion of the total number of taxa found in all samples than any other single substratum type. As a result, Pinder et al. (1987) recommended that, for surveillance purposes, macroinvertebrate sampling in chalk streams should be confined to the gravel fauna.

In addition to taking core samples Pinder et al. (1987) also sampled the gravel fauna by kick-sampling, for 20 seconds at a time, using a standard FBA pond-net of 1 mm mesh. Fifteen replicate kick-samples were taken in May and in September.

The numbers of animals taken in kick and core samples were virtually identical in September (1376 from kick-sampling and 1372 from cores) but in

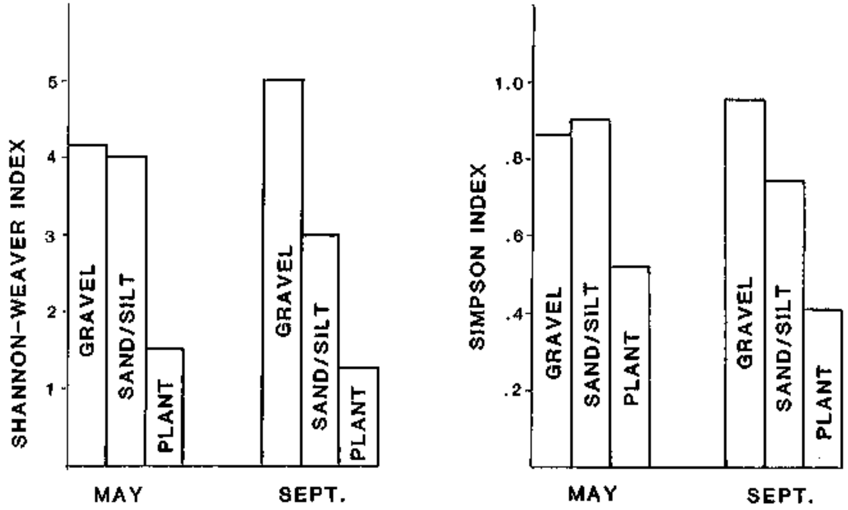

FIG. 2. Values of two indices of diversity in May and September, based on fauna of gravel, soft sediment (sand/silt) and *R. calcareus* (plant).

May almost twice as many individuals resulted from kick-sampling (9185) as from cores (4823). The difference in May was accounted for, almost entirely, by Ephemeroptera (mainly *Baetis* spp.) which probably resulted from their marked tendency to enter the drift when physically disturbed (Williams 1981). Otherwise, differences between the two types of sample were slight, except that the relative abundance of small organisms, notably Chironomidae and Hydracarina was consistently underestimated by kick-sampling because of the coarse mesh of the sampling net.

Such considerations are, however, of minor importance in routine surveillance as they have rather little effect on derived indices. Kick-samples are speedily obtained and for this reason Pinder et al. (1987) recommended this method. Ten sampling units of either type were sufficient to yield at least 90% of the species obtained in the complete sample of 15 units taken on each occasion. This represents 200 seconds of kick-sampling or a total area of 0·175 m^2 taken by core-sampling.

Level of identification

The level to which macroinvertebrates need to be identified is largely predetermined, in the case of biotic indices, such as the Chandler Score and more especially the BWMP Score, by the requirements of the particular index.

Diversity indices, on the other hand, consider the distribution of individuals among taxa and their value is therefore likely to vary according to the

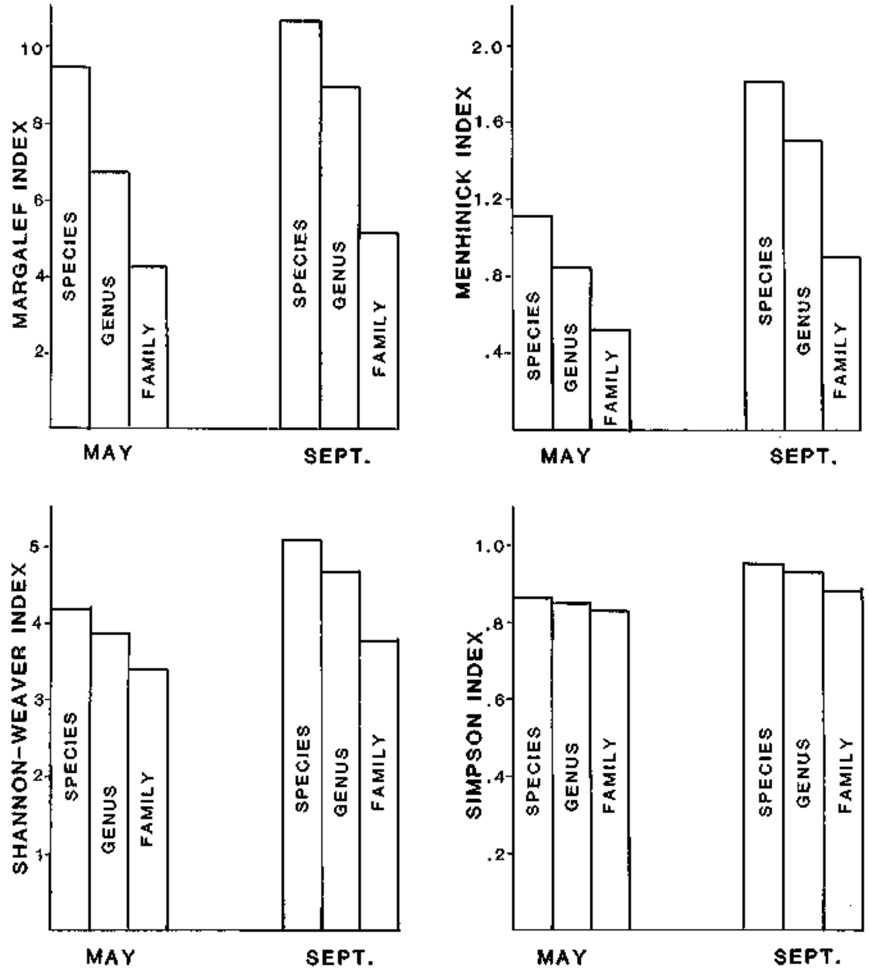

FIG. 3. Four indices of the diversity of gravel fauna in May and September showing the effect of identifying to different taxonomic levels.

number of taxa which are recognized. This will in turn depend upon the amount of time and the level of expertise which is available.

The Margalef and Menhinick indices were affected by the taxonomic level to a much greater extent than either the Simpson Index or the Shannon-Weaver Index (Fig. 3). The Simpson Index was least affected of the four. Family diversity estimated by this method was more than 90% of the value estimated for species. Pinder et al. (1987) therefore recommended Simpson's Index as being the most useful measure of diversity for surveillance purposes and concluded that the effort required to identify beyond family level could not be justified in this context. Bournaud & Keck (1980) also found this to be a useful measure of diversity in their study of the macroinvertebrates in a French chalk-stream.

Temporal and spatial variation

The extent of variation in macroinvertebrate communities with time and the effect of this on the ability of derived indices reliably to reflect differences in water quality in time or space, is an important consideration in the interpretation of data resulting from surveillance programmes. Relatively few authors have taken account of this. The work of Murphy (1978) is a notable exception and Armitage et al. (1983) considered the effect of sampling at different seasons on values obtained for the BMWP Score.

Pinder & Farr (1987a) selected 5 sites (Fig. 1), spaced more of less equidistantly on the River Frome, at which the gravel fauna was sampled at two-monthly intervals over an 18-month period. For each date they estimated two qualitative biotic scores (Chandler and BMWP) and two indices of diversity (Shannon-Weaver and Simpson). In addition, the Average Score per Taxon was calculated for each Biotic Score by dividing the total score by the number of taxa contributing to it.

Temporal variability in each Biotic Score was much greater than in their respective Average Scores per Taxon (Table 1). Diversity indices were rather less variable than Total Biotic Scores, but much more so than the Average Scores per Taxon (Table 1).

Although the underlying temporal variation in all indices was usually sufficient to obscure differences between sites (Pinder & Farr 1987a) the mean values of the Chandler and BMWP Scores were significantly lower at the most upstream site (Station 1, Fig. 1) than at any of the four sites further downstream (Fig. 4), implying a poorer water quality at this site. This accords with the results of Biochemical Oxygen Demand (BOD) determinations and other direct measures of water quality (Pinder & Farr 1987a). The Average BMWP Score per Taxon also isolated Station 1 (Fig. 4) but the Average Chandler Score per Taxon did not. Murphy (1978) recommended using the latter because it did not have "depressed values associated with wide ranges of physical conditions at headwater sites". The work reported by Pinder & Farr (1987a) suggests that, in some situations at least, it is also rather insensitive to

TABLE 1. Coefficients of variation (s/x) with time, amongst scores and indices at each site.

	BIOTIC SCORES				*DIVERSITY INDICES*	
	CHANDLER SCORE	*CHANDLER ASPT*	*BMWP SCORE*	*BMWP ASPT*	*SHANNON-WEAVER*	*SIMPSON*
STATION 1	0·28	0·09	0·27	0·06	0·19	0·16
STATION 2	0·15	0·04	0·12	0·05	0·14	0·12
STATION 3	0·21	0·06	0·15	0·06	0·07	0·02
STATION 4	0·15	0·05	0·12	0·06	0·09	0·04
STATION 5	0·26	0·05	0·10	0·05	0·12	0·06

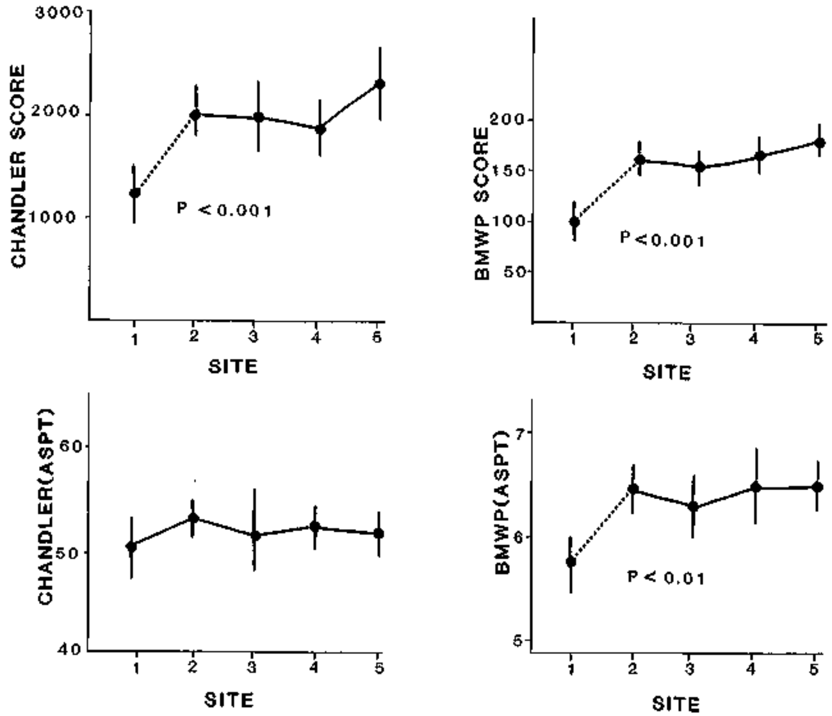

FIG. 4. Mean values, over an 18-month period, (95% confidence limits indicated) of two biotic scores and the corresponding Average Scores per Taxon (ASPT) for five sampling sites (see Fig. 1).

Broken lines indicate a significant difference between adjacent sites.

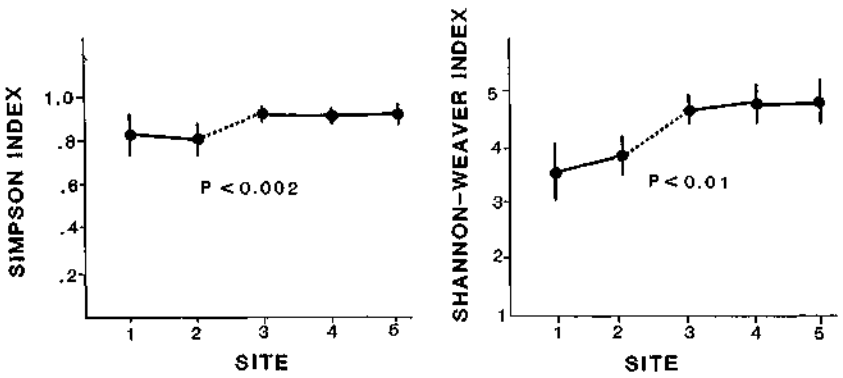

FIG. 5. Mean values, over an 18-month period, (95% confidence limits indicated) of two indices of diversity for five sampling sites (see Fig. 1).
Broken lines indicate a significant difference between adjacent sites.

slight differences in water quality and may therefore have less widespread usefulness than Murphy thought.

The two indices of diversity differed from the biotic indices in that their mean values at Stations 1 and 2 were not significantly different from one another, but were significantly lower than at any of the three sites further downstream (Fig. 5). In this case the predominant influence appeared not to be water quality, since Station 2 was not significantly different from the sites further downstream but appeared to have a somewhat higher water quality than Station 1 (Pinder & Farr 1987a). Presumably the range of variation in physical conditions and the less complex habitat structure in the headwaters was responsible for the lower diversity at these two sites.

Responses of indices to organic pollution

Pinder & Farr (1987b) investigated a series of sites on the River Frome and its tributaries, at which there was visible evidence of organic pollution. Two of these were associated with minor discharges of sewage, one with a ditch which intermittently carried low grade farmyard effluent and one with a fish-farm. None of the sites could be regarded as being seriously polluted.

The relationships between several indices and more direct measures of water quality are summarized in Table 2 (after Pinder & Farr 1987b). The Chandler Score did not show a significant correlation with any measure of water quality, although the Average Chandler Score per Taxon was significantly ($P<0{\cdot}05$) and negatively correlated with BOD and levels of dissolved organic carbon (DOC). Values of the BMWP Score were significantly ($P<0{\cdot}05$), negatively correlated only with DOC whereas the Average BMWP Score per

TABLE 2. Correlation coefficients and significance levels (n.s. = not significant, * = $P<0{\cdot}05$, ** = $P<0{\cdot}01$) between indices based on macroinvertebrate community and direct measures of water quality.

	WATER QUALITY DETERMINANDS				
	Total BOD	*Carbonaceous BOD*	*Dissolved Organic carbon*	*Particulate Organic carbon*	*Suspended Solids*
BIOTIC SCORES					
BMWP SCORE	−0·682 n.s.	−0·738 n.s.	−0·822 *	−0·134 n.s.	−0·641 n.s.
BMWP ASPT	−0·973 **	−0·941 **	−0·641 n.s.	−0·426 n.s.	−0·860 *
CHANDLER SCORE	−0·578 n.s.	−0·610 n.s.	−0·482 n.s.	+0·137 n.s.	−0·563 n.s.
CHANDLER ASPT	−0·891 **	−0·858 *	−0·760 *	−0·520 n.s.	−0·732 n.s.
DIVERSITY INDICES					
SIMPSON INDEX	+0·633 n.s.	+0·671 n.s.	+0·963 **	+0·275 n.s.	+0·540 n.s.
SHANNON-WEAVER INDEX	+0·690 n.s.	+0·742 n.s.	+0·898 **	+0·140 n.s.	+0·694 n.s.

Taxon showed a highly significant ($P<0{\cdot}01$), negative correlation with BOD (Fig. 6a) and a significant ($P<0{\cdot}05$) negative correlation with the concentration of suspended solids. Both the Simpson and Shannon-Weaver Indices were highly significantly ($P<0{\cdot}01$) but positively correlated with levels of DOC (e.g. Fig. 6b).

It is generally assumed that environmental 'stress' has the effect of reducing faunal diversity. Within the range of conditions encountered in the River Frome system, however, deterioration in water quality, resulting from organic inputs had the opposite effect. The positive correlation, observed between diversity and DOC suggests that such inputs probably enhanced microbial production, thereby increasing the quality or quantity of food available to macroinvertebrates.

Consideration of average biotic score per taxon, together with the corresponding total score may be more informative than either taken in isolation. At some sites, for example below the ditch carrying farm effluent and below a fish-farm, total BMWP Score and Average BMWP Score per Taxon were both depressed, indicating a straightforward reduction in water quality. In contrast, below an input of partially treated sewage effluent, Pinder & Farr (1987b) found that whereas the Average Score per Taxon was depressed, values obtained for the total BMWP Score were greater than those from a site further upstream. Pinder & Farr (1987b) interpreted these results as indicating a region of organic 'enrichment' rather than of 'pollution'.

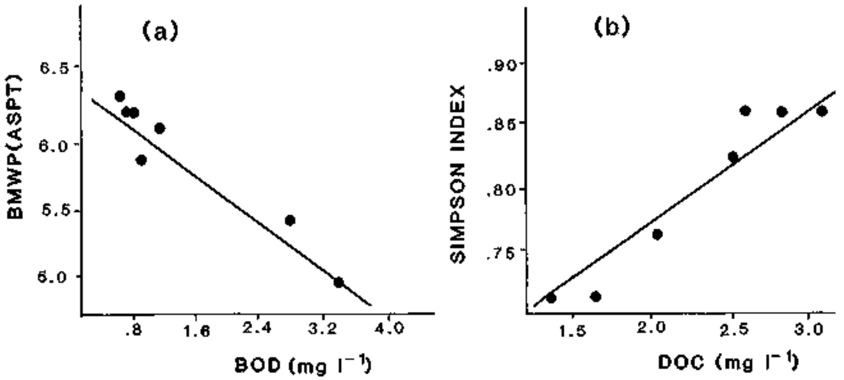

FIG. 6. Relationship between (a) average BMWP Score per Taxon (BMWP (ASPT)) and Biochemical Oxygen Demand (BOD) and (b) Simpson Index of diversity and dissolved organic carbon concentration.

Pinder & Farr (1987b) considered the BMWP Score to be superior to the Chandler Score for surveillance purposes, because it is simpler to estimate and because of the apparent ability of the Average BMWP Score per Taxon to respond to relatively slight changes in water quality. They offered a criticism of the method of calculating the score, however, on the grounds that it allocates a value of 2 to Chironomidae and 1 to Oligochaeta, regardless of the species which are present. Both of these taxa contain a large number of species and are almost universally present in freshwater. While some species are very tolerant of organic pollution others are not. Their inclusion in the Score without further discrimination has the general effect of depressing the Average Score per Taxon, while having a negligible effect on the total score.

On the other hand, both groups contain well known tolerant species which, if present in any but very small numbers, are truly indicative of organic pollution (e.g. *Chironomus riparius* and *Tubifex tubifex*). Pinder & Farr (1987b) found that the effect of ignoring the presence of Oligochaeta and Chironomidae, except for these two species, was to markedly increase the value of the Average BMWP Score per Taxon upstream of an organic effluent, thereby rendering the depressive effect of the effluent much more apparent.

Such a refinement increases the amount of taxonomic effort which is required, but this may well be justified in situations where additional sensitivity is required to detect even a slight deterioration in water quality. Chalk-streams, in view of their highly valued fisheries and high water quality may well be regarded as just such a situation.

The value of diversity indices lies in the fact that they incorporate no assumptions as to the type of stress to which the biota are likely to be

subjected. For this reason they will continue to have a function in surveillance in situations where pollution other than by organic effluents is likely.

Acknowledgements

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THE DESIGN AND DEVELOPMENT OF THE 'WINDERMERE PROFILER'

AN INSTRUMENT FOR MEASURING HOW VARIOUS ENVIRONMENTAL PARAMETERS VARY WITH DEPTH IN LAKES, RESERVOIRS AND RIVERS

M. A. ROUEN

Introduction

Profiles of temperature and dissolved oxygen concentration are routinely taken in three lakes in the English Lake District as part of the Freshwater Biological Association's long term research programmes. These measurements are normally taken every week during summer months and every fortnight during winter months. This has given the FBA valuable long-term data sets which, when combined with meteorological, chemical and/or biological data, can be used to test models and provide evidence of trends and cycles (e.g. George & Harris 1985; Heaney et al. 1988). Profiles of these and other parameters are also required as basic data for a whole range of short term field studies. Until recently, these data sets have been gathered by scientists using a number of commercially available instruments, each independently powered and with its own probe system and meter (e.g. Heaney & Talling 1980; Jewson et al. 1984). This method is cumbersome and requires great discipline by the scientist. Talling (1981) has discussed some of the problems in the context of the advantages of an earlier type of profiling instrument. In adverse weather conditions, there is a temptation to record readings before the probes have equilibrated and the analogue meters are always difficult to read in a rocking boat.

It was clear that such data could be gathered more easily if measurements could be made using a single instrument and with at least a degree of automation. The design of such an instrument should permit the addition of further transducers when required. A completely unmanned, fully automatic