Freshwat. Biol. 1974, Volume 4, pages 213–222

With compliments and thanks: Peter M. Nuttall

Numerical indices applied to the results of a survey of the macro-invertebrate fauna of the Tamar catchment (southwest England)

P.M. NUTTALL *and* J.B. PURVES *Cornwall River Authority, Launceston, Cornwall, England*

Manuscript accepted 7 July 1973

Summary
A survey of the macro-invertebrate fauna in the River Tamar revealed that a division of the catchment can be made which separates an organically enriched upper region from a more stable environment in the lower tributaries and reaches. Invertebrate species normally associated with organic pollution were found immediately downstream from farm waste and sewage effluent outfalls. Invertebrate species normally associated with an unpolluted condition were widely distributed throughout the catchment, and revealed that the Tamar is essentially free from gross pollution causing the continuous elimination of stream fauna. Systems used by pollution control organizations to codify biological results are reviewed and applied comparatively to the results. The Diversity index was found to be the most consistent method in assessing the biological state of the river. The Trent, Lothian, Chandler and Carpenter indices were found to give either anomalous figures or proved insensitive to conditions beyond a certain quality.

Introduction

Systems for evaluating water quality by analysis of the organisms present have been devised by several workers. Kolkwitz & Marsson (1908, 1909) first put forward the concept of differing zones of pollution each containing characteristic animals and plants. The 'Saprobiensystem' has since been revised by several authors including Liebmann (1951, 1959) and Fjerdingstad (1964), and reviewed by Schwoerbel (1970). Diatoms (Patrick, 1954), algae (Butcher, 1946; Palmer, 1969) and stream plankton (Brinley, 1942) have been used in classifying water quality with regard to organic pollution. Other schemes have been described by Patrick (1950, 1951) and Wurtz (1955), and are reviewed by Hawkes (1972). Brinkhurst (1967) suggested that the percentage of *Limnodrilus hoffmeisteri* in relation to all other oligochaetes may prove to be a useful indicator of organic pollution. Surber (1953), Beck (1955) and Gaufin (1958) described systems using groups of macro-invertebrates according to their tolerance to organic pollution and these are reviewed by Thomas, Goldstein & Wilcox (1973).

Schemes adopted by river authorities in Britain tend to rely on species or groups

Correspondence: Mr P. M. Nuttall, Cornwall River Authority, St John's, Western Road, Launceston, Cornwall, England.

of easily identified benthic macro-invertebrates. Carpenter (1926) described four classes of groups of animals by which a biological classification of water quality could be made. Hawkes (1956) and Bielby (1960) distinguished zones of macro-invertebrates according to the intensity of pollution. A biotic index devised by Woodiwiss (1964) for use on the Trent river system relied on the sensitivity of groups to pollution and on the number of component groups in a sample. This was adapted by Graham (1965) into the Lothian index, while Chandler (1970) designed a 'score' system to include an abundance factor for different species according to their tolerance to organic pollution. Edwards *et al.* (1972) described a Diversity index devised by Margelef (1956)

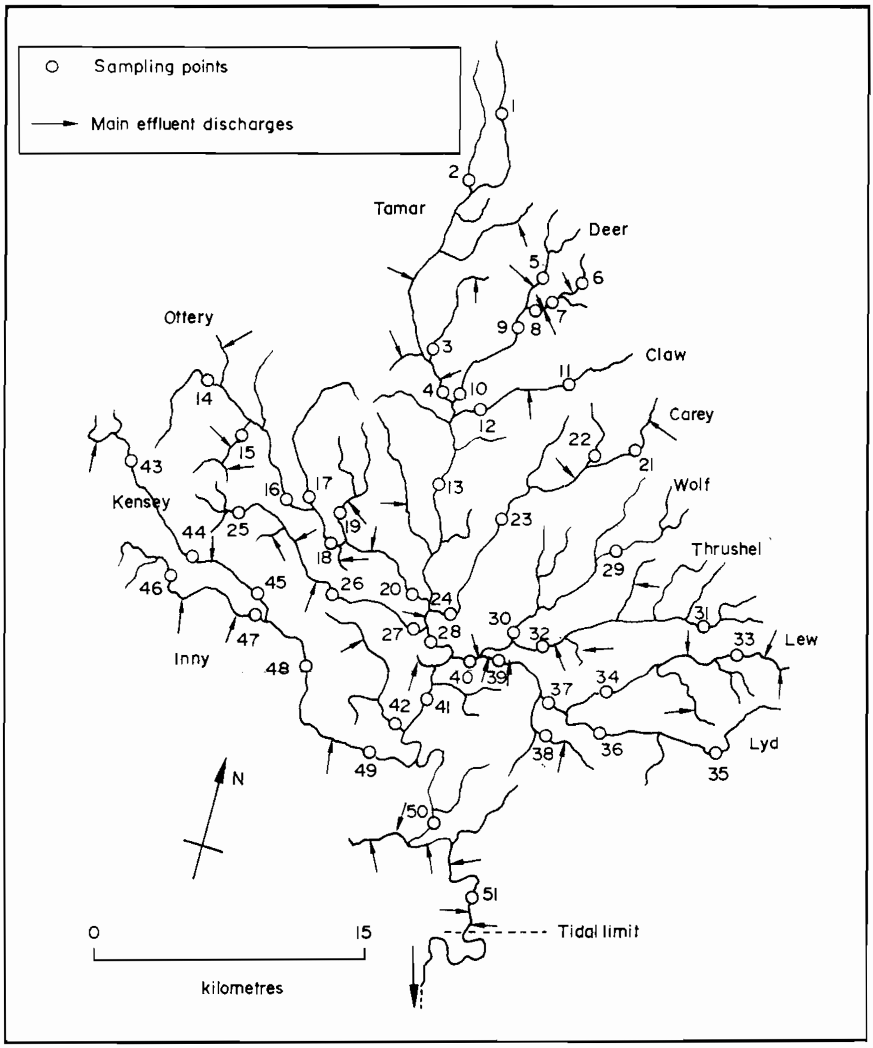

Fig. 1. Map of River Tamar and its principal tributaries showing sampling stations (1–51) and sites of main effluent discharges.

which gives a numerical assessment of the number of component groups and the balance of these groups within a community, whilst ignoring the requirements of individual species upon which the indicator concept and biotic index rely.

The following paper describes a faunal survey of the Tamar catchment conducted over the period 1971–72. Biotic indices and the Diversity index currently in use by pollution control organizations in Britain are applied to the biological results in order that comparabilities between the systems could be established.

Description of study area

The River Tamar flows south from the agricultural lowland of Devon and North Cornwall to discharge into the English Channel at Plymouth. It has a catchment area of 923 km^2 above Gunnislake tidal weir (NGR SX 435 709), a mean summer (April–September) flow of 11·84 m^3/sec and a mean winter flow of 35·22 m^3/sec. There are ten major tributaries as shown in Fig. 1.

Treated sewage from a large number of small works, farm waste and agricultural land run-off are the main effluents to the river. The outfall from many of the treatment works is normally less than 1000 gal/h. Cooling water and milk-product wastes are the only industrial effluents to the river above the tidal limit. Apart from Plymouth, which is situated on the estuary, there are no large centres of population or industrial development through which the river flows.

The headstreams of the Tamar drain agricultural lowland and are consequently slow-flowing with a mud and silt substrate. The lower tributaries of the Tamar, however, are fast-flowing streams which drain the moorland areas of Dartmoor to the east and Bodmin to the west and have a stone and gravel substrate.

Moss (*Fontinalis* sp.) and algae (*Mougeotia* sp. and *Spirogyra* sp.) locally form dense mats in the streams during summer. Higher plants are generally widespread and abundant throughout the catchment. An algal bloom, dominated by the species *Anacystis* cf. *A. thermalis* has occurred over the past years at Tamar Lake at the head of the river, and is indicative of progressive eutrophication associated with agricultural run-off.

The Tamar and tributaries support a rich population of brown trout, migratory trout (*Salmo trutta*) and salmon (*Salmo salar*) (Cornwall River Authority, 1972). Dace (*Leuciscus leuciscus*), grayling (*Thymallus thymallus*), eel (*Anguilla anguilla*), millers thumb (*Cottus gobio*), stone loach (*Nemacheilus barbatulus*), minnow (*Phoxinus phoxinus*) and brook lamprey (*Lampetra planeri*) are also found locally in the catchment.

Water quality

The Cornwall River Authority has taken regular samples at forty-three stations on the Tamar and major tributaries. The results of analyses show that the ratio between permanganate value (PV) and biological oxygen demand (BOD) is within the range 2·15–3·86 : 1 throughout the catchment. The pH value in the Tamar tends to be higher (average pH = 7·8 range 6·8–7·9) when compared with other rivers in the area, and this can be associated with the effect of agricultural run-off. There are overall low nitrate nitrogen (average 1·9 mg/l range 1·1–5·2 mg/l) and phosphate (average 0·46 mg/l range 0·1–3·4 mg/l) values, with a change in water colour as the sampling points approach the tidal limit.

Fauna

Methods

A total of ninety-eight samples were taken from fifty-one stations on the Tamar catchment during 1971 (July–August) and 1972 (March–April). Samples were taken with an FBA net (sixty-four meshes/cm^2) from the riffle section of the river. The bottom of the river was disturbed by kicking and allowing the current to carry the dislodged material into the net (Elliott, 1971). By slowly moving upstream for a fixed period of 2 min, this technique ensured collecting a representative quantity of material over a large area of bottom.

Samples thus obtained were washed from the net into a collecting tray, concentrated using part of the collecting net, and put into a polythene container with 4% formalin as preservative.

In the laboratory, samples were individually washed with tap-water in an Endecott sieve (140 meshes/cm^2) and then transferred to a large sorting tray (35 × 26 cm) marked out by grid lines into six equal divisions. Animals were picked out from one or one to six of the divisions according to the amount of material present, and placed in a Petri-dish for counting. Large animals and members of each species present were also removed and placed in a separate Petri-dish for identification.

Distribution

A total of eighty-two taxa were identified from all samples, of which fifty-six were at specific level. Chironomidae, Baetidae and Tubificidae were found at nearly all stations, summer and winter. *Leuctra* spp., *Ephemerella ignita*, Elminthidae, *Dicranota* sp., *Hydrobia jenkinsi*, *Hydropsyche instabilis*, *Gammarus pulex*, Naididae, Simuliidae and *Rhithrogena semicolorata* were found at forty or more stations, either summer or winter. Figure 2 shows the distribution and abundance of the major animal groups within the Tamar catchment over the period 1971.

The freshwater shrimp, *Gammarus pulex* was widely distributed in the Tamar catchment. This animal is sensitive to suspended material and intolerant of deoxygenation (Hynes, 1960). Macan (1963) has suggested that it is unable to withstand a pH below 7. Suspended solids are normally low in the Tamar system, apart from periods of heavy spate, and the average pH has been given as 7·8. *Asellus meridianus* was almost completely absent, being found in small numbers immediately downstream of organic waste discharges at stations 5, 8 and 10. In organically polluted rivers, *Asellus* replaces *Gammarus* on eroding substrata on which it is otherwise rare (Hawkes, 1972).

The stoneflies, which generally are regarded as intolerant of pollution (Hynes, 1960) were widely distributed in the catchment, with *Leuctra* spp. as the most abundant summer form. However, stoneflies were totally absent from stations 3, 8, 9 and 27, either summer or winter, and this was associated with organic enrichment from sewage effluent or farm waste entering the river upstream of sampling points.

Thirteen species of mayfly were found, most of which were widely distributed in the catchment. *Rhithrogena*, normally the least tolerant of the mayflies to organic pollution, was abundant and occurred at forty stations in the river during March–April. Both *Baetis rhodani* and *B. muticus* occurred in the catchment. *B. rhodani*, which is known to be fairly tolerant of organic pollution (Hawkes, 1972) was the most abundant insect. Much less is known about the responses of *B. muticus*, although Macan (1963) associates it with *B. rhodani* in small, stony streams and rivers. *Baetis*

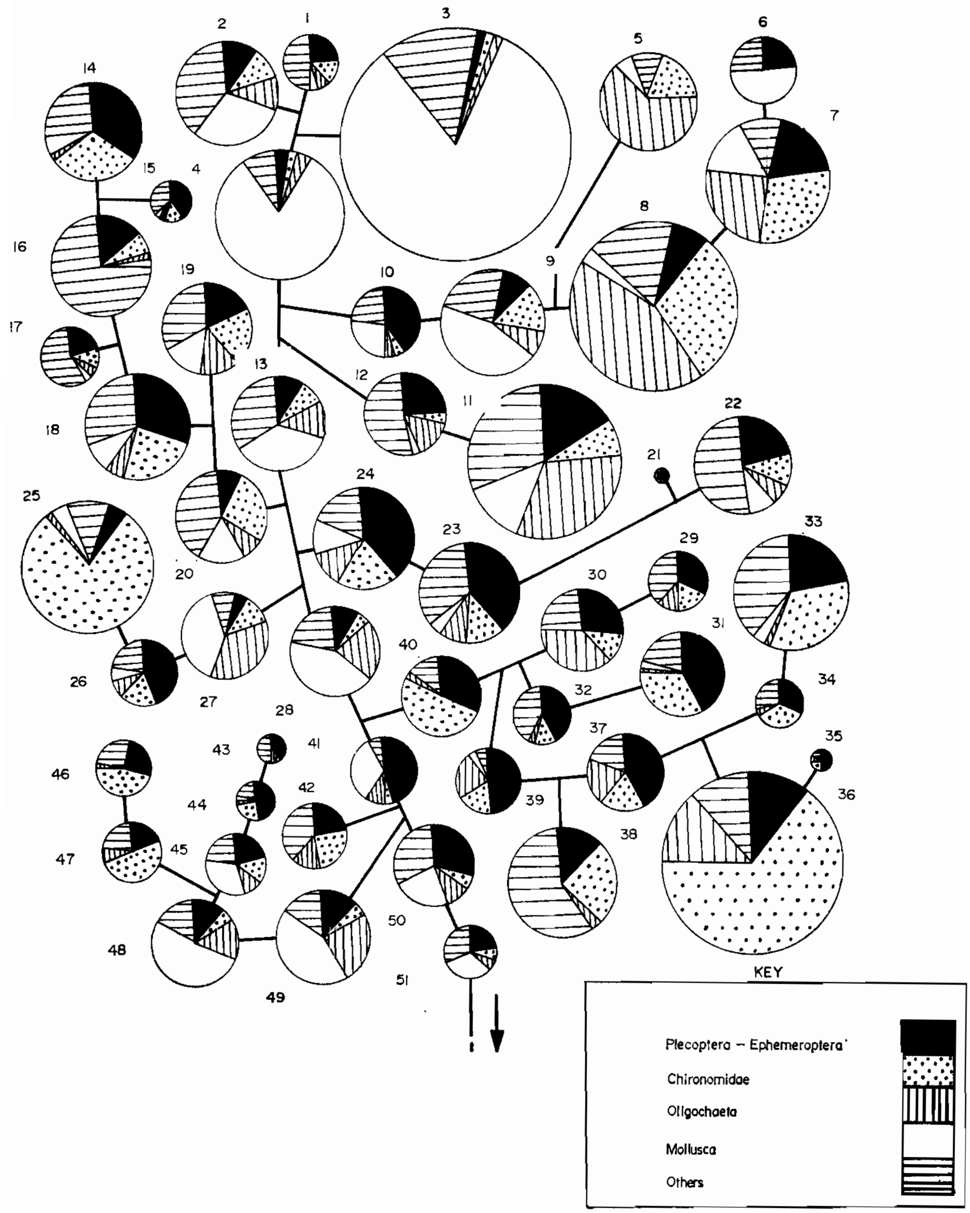

Fig. 2. Composition and abundance of the major macro-invertebrate groups in the Tamar catchment. —, 1971; — — —, 1972.

niger showed a restricted distribution in the catchment in streams supporting abundant growths of vegetation. *Ephemerella ignita*, which is rarely found under polluted conditions (Langford & Bray, 1969) was frequent at forty stations in the catchment during summer.

Caddis-flies were present at most of the sampling stations. The species most widely distributed in the Tamar catchment was *Hydropsyche instablis* which is known to be tolerant of mild organic pollution (Schuhmacher & Schremmer, 1970) but sensitive to suspended inorganic particles (Hynes, 1960) which impair the net feeding mechanism.

Aquatic coleopterans were frequent throughout the catchment, with larvae of *Limnius volckmari*, most abundant. This species, like other Elminthid beetles is generally considered intolerant to low oxygen concentrations associated with organic pollution (Learner *et al.*, 1971). In the Tamar system oxygen concentrations are normally high.

Larvae of Chironomidae were present at nearly all stations. Certain species of this group are known to be favoured by organic enrichment (Hawkes & Davies, 1971). However, as the majority of these animals were identified only to family level, little comment can be made concerning their distribution in relation to pollution levels. *Chironomus thummi* which is regarded as quite tolerant to gross organic pollution (Hawkes, 1972) was found in large numbers in association with sewage fungus at station 43 during early summer 1971 as a result of milk-product waste entering the river.

Of the freshwater snails, *Hydrobia jenkinsi* was most abundant in the upper Tamar and tributaries associated with organic enrichment from sewage effluent and farm waste discharges. Hynes (1960) comments that the presence of molluscs in streams is favoured by organic enrichment. The Tamar system, however, is low in dissolved calcium and magnesium salts and consequently supports a limited mollusc population of typical soft-water species.

The oligochaete worms, principally naidids and tubificids, occurrred at nearly all stations in the catchment, both summer and winter. Tubificids were most abundant at stations in the upper Tamar and River Deer associated with agricultural run-off and sewage effluent. The tubificids are detritus feeders and rely mainly on organic particles within the substrate (Hynes, 1960). Naidid worms, however, are essentially inhabitants of soft substrata in the depositing region of rivers (Hynes, 1960) and where the environment becomes enriched by organic material then large populations occur (Learner *et al.*, 1971).

Numerical assessment

The Carpenter index (Carpenter, 1926) adapted by the Department of the Environment (1970) for the River Pollution Survey distinguishes water quality according to four classes, A, B, C and D each containing characteristic groups of animals indicative of clean to polluted conditions.

The Trent index (Woodiwiss, 1964) overcomes many of the objections voiced against the 'indicator concept' (Hynes, 1960) by calculating an empirical index of pollution. Invertebrates are sorted into groups which consist of species, genus or family units. Six of these groups are given key status according to their sensitivity to pollution. The number of groups in a sample, together with the dominant key groups, are used to calculate the biotic index. Clean streams score an index of 10 and this number is reduced with increasing pollution to 0 representing septic conditions. The Lothian index (Graham, 1965) is similar to the Trent system, but has a six-point scale so that clean streams score an index of 1 and higher values indicate increasing pollution.

The 'score' system devised by Chandler (1970) also depends upon the sensitivity of organisms to pollution, but the list of animals is more detailed than either Woodiwiss (1964) or Graham (1965). The Chandler index also has the advantage of taking into account the number of each taxon present, thus avoiding the chance occurrence of animals in samples through such phenomena as drift.

The Diversity index (Margelef, 1956) is an expression which reflects the number of component groups and the numerical balance of these groups while ignoring the

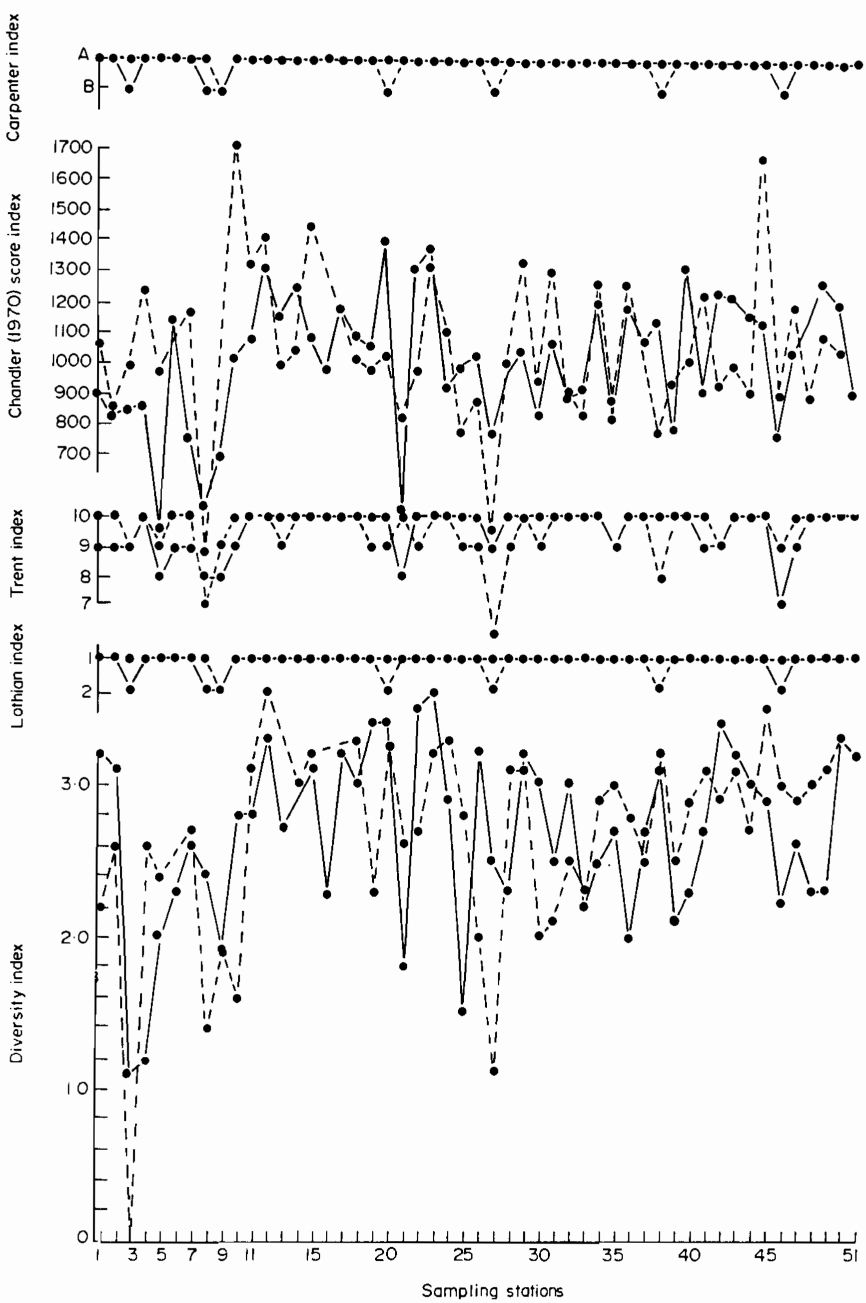

Fig. 3. Comparative values for the Trent, Carpenter, Lothian, Candler and Diversity indices from samples in the Tamar catchment.

requirements of different species. The index increases as the number of groups increase and their representation becomes equal, from the expression

$$\text{Diversity} = -\Sigma^{t}\left(\frac{ni}{N}\log_2\frac{ni}{N}\right)$$

where t = number of groups in the sample
n = number of individuals in each group
N = total number of individuals in the sample.

The group can be defined as the lowest taxonomic unit to which all organisms can be identified, which in this survey was the family taxon.

Comparative values for each sample are given for the Trent, Lothian, Carpenter, Chandler and Diversity indices in Fig. 3.

Discussion

Essentially, the Tamar catchment is free from gross pollution causing the continuous elimination of stream fauna. However, a division of the catchment can be made which separates an organically enriched upper region from a more stable environment on the lower tributaries and reaches of the Tamar according to the invertebrate communities found there. The primary cause of enrichment is agricultural run-off, with sewage discharges in the upper region supporting local zones of pollution tolerant species in the river immediately downstream of outfalls.

Although claims that the formal classification of biological conditions are undesirable (Hynes, 1960), workers in pollution control organizations need to codify their findings as an explanatory simplification for non-biologists (Hawkes, 1972). However, such schemes as the Trent biotic index, the Lothian index, the Carpenter index and the Chandler index rely on the often insufficient knowledge of the tolerance of individual species to pollution, whereas the Diversity index is independent of sensitivity as well as of sample size (Mackay, Soulsby & Poodle, 1973).

In polluted streams, the Diversity indices range from 0·4 to 1·5 (Wilm, 1970), Lothian indices range from 6 to 3 (Graham, 1965). Trent indices range from 0 to 8 (Marstrand, 1973), Chandler indices range from 0 to 400 (Marstrand, 1973) and the Carpenter indices range from D–C (H.M.S.O., 1971). From this, the Lothian and Carpenter index classified all stations in this survey as unpolluted. The Chandler index demonstrated pollution at station 8 and the Trent index demonstrated pollution at Stations 8 and 27, but failed to distinguish the effects of moorland run-off from pollution at Station 46. The diversity index demonstrated pollution at Stations 3, 4, 8, 25 and 27. These were found to be the result of either farm waste or sewage effluent

Table 1. Range of values for the Trent, Carpenter, Lothian, Chandler and Diversity indices from samples in the Tamar catchment, using the Trent index as the base

Trent	Lothian	Carpenter	Chandler	Diversity index
10	1	A	791–1710	1·2–3·6
9	2–1	B–A	757–1133	1·1–3·4
8	2–1	B–A	465–783	1·8–3·2
7	2–1	B–A	383–762	1·4–2·2
6	2	B	420	1·1

entering the river upstream of sampling points. The Diversity index also distinguished the effects between pollution and low numbers of individuals of occasional species caused by moorland run-off in the head-streams of the Lyd and Inny systems (Fig. 1).

Using the Trent index as a base, the range of values given for Trent grades in this survey by the other four systems are shown in Table 1. The Trent and Lothian systems lack range in assessing clean water conditions. The Carpenter index, although of elemental use in the classification of biological conditions, appears to be totally inadequate for pollution control studies on account of its loosely described and inexact divisions between groups. A considerable overlap is shown (Table 1) between ranges of the Chandler index and the Diversity index to other systems. This is to be expected since the 'score' system and Diversity index attempt to give a continuous assessment of conditions, while the Trent and Lothian schemes classify the main characteristics of polluted water.

The Trent, Lothian and Diversity indices are fairly quick to apply, although the latter requires computer time. The Chandler index, however, is considerably involved and takes much longer than other methods discussed in this paper.

The Trent, Lothian and Chandler indices may require adaptation to local conditions (Marstrand, 1973) since they were devised specifically for the areas of initial application using organisms from those area. The Diversity index, however, is applicable to rivers in widely separate watersheds (Mackay *et al.*, 1973) and therefore needs no adaptation to local conditions. Sampling procedure is the same for all four systems although the Diversity index has the advantage of being independent of sample size.

Although Marstrand (1973) suggested that the Trent index or an adaptation of it to suit local conditions would be the most useful method of assessing polluted waters, we find that the Diversity index is the most useful system of coding biological findings, and of the indices studied in this paper, the least likely to produce anomalous results.

Acknowledgment

We are most grateful to the staff of the Cornwall River Authority who aided us in a number of ways, and for permission to publish data held under the auspices of the Authority. The opinions expressed in this paper are the authors', and do not necessarily agree with those of the Cornwall River Authority.

References

Beck W.M. (1955) Suggested method for reporting biotic data *Sew. industr. Wastes*, **27**, 1193–1196.

Bielby G.H. (1960) The Biology of river pollution with reference to the Bristol Avon River Board Area. *J. Inst. Sew. Purif.* **3**, 298–306.

Brinkhurst R.O. (1967) The distribution of aquatic oligochaetes in Saginaw Bay, Lake Huron. *Limnol. Oceanog.* **12**, 136–143.

Brinley F.J. (1942) Biological studies, Ohio River Pollution Survey *Sewage Works J* **14**, 147–159

Butcher R.W. (1946) The biological detection of pollution, *J. Inst. Sew. Purif.* **2**, 92–97.

Carpenter K.E. (1926) The lead mine as an active agent in river pollution. *Ann. appl. Biol.* **13**, 395–401.

Chandler J.R. (1970) A biological approach to water quality management. *Wat. Poll. Control*, **4**, 415–422.

Cornwall River Authority (1972) *River Tamar Fisheries Survey*. Report of the Cornwall River Authority, Launceston, Cornwall.

Department of the Environment (1970) *Report of a River Pollution Survey of England and Wales*. Her Majesty's Stationery Office, London.

Edwards R.W., Benson-Evans K., Learner M.A., Williams P., Williams R. (1972) A biological survey of the River Taff. *Wat. Poll. Control*, **2**, 144–166.

Elliott J.M. (1971) Statistical analysis of samples of benthic invertebrates *Scient. Publs. Freshwat. biol. Ass.* **25**.

Fjerdingstad E. (1964) Pollution of streams estimated by benthonic phytomicro-organisms. *Int. Rev. Hydrobiol.* **49**, 63–131.

Gaufin A.R. (1958) The effects of pollution of a Midwestern stream. *Ohio J. Sci.* **58**, 197–201

Graham T.R. (1965) A Biological index of pollution. Annual Report, *Lothians Purif. Board*, 16–26.

Hawkes H.A. (1956) The biological assessment of pollution in Birmingham streams. *J. Inst. munic. Eng.* **82**, 425–436.

Hawkes H.A. (1972) Biological aspects of river pollution. In: *River Pollution*, 2, *Causes and Effects.* 5th edn. Ed. by L. Klein. pp. 311–432. Butterworth, London.

Hawkes H.A. & Davies L.J. (1971) Some effects of organic enrichment on benthic invertebrate communities in stream riffles. *11th Symposium British Ecol. Soc., The Scientific Management of Animal and Plant Communities for Conservation.* Ed. by Duffey & Watt, 261–293.

Hynes H.B.N. (1960) *Biology of Polluted Waters.* Liverpool University Press.

Kolkwitz R. & Marsson M. (1908) Okologie der pflanzlichen Saprobein. *Ber. dt. bot. Ges.*, 26(a), 505–519.

Kolkwitz R. & Marsson M. (1909) Okologie der tierischen Saprobien. *Int. Rev. Hydrobiol.* **2**, 126–152.

Langford T.E. & Bray E.S. (1969) The distribution of Plecoptera and Ephemeroptera in a lowland region of Britain (Lincolnshire). *Hydrobiologia*, **35**, 243–271.

Learner M.A., Williams R., Harcup M. & Hughes B.D. (1971) A survey of the macro-fauna of the River Cynon, a polluted tributary of the River Taff (South-Wales). *Freshwat. Biol.* **1**, 339–367.

Liebmann H. (1951) *Handbuch der Frischwasser und Abwasser-Biologie.* Vol. 1, Oldenburg-Verl, Munich.

Liebmann H. (1959) *Handbuch der Frischwasser- und Abwasser-Biologie.* Vol. 2, Oldenburg-Verl. Munich.

Macan T.T. (1963) *Freshwater Ecology.* Longmans, London.

Mackay D.W., Soulsby P.G. & Poodle T. (1973) The biological assessment of pollution in streams. *Ass. River Authorities Year Book and Directory*, 189–197.

Margelef R. (1956) Information y diversidad espicfica en las corminudades de organismos. *Inv. Pesq.* **3**, pp. 99.

Marstrand P. (1973) Using biotic indices as a criterion of in-river water quality. *Ass River Authorities Year Book and Directory*, 182–188.

Palmer C.M. (1969) A composite rating of algae tolerating organic pollution. *J. Phycol.* **5**, 78–82.

Patrick R. (1950) A biological measure of stream conditions. *Sew. industry. Wastes*, **22**, 926–938.

Patrick R. (1951) A proposed biological measure of stream conditions. *Verh. int. Ver. Limnol.* **11**, 299–307.

Patrick R. (1954) Diatoms as an indication of river changes. *Proc. 9th Ind. Wastes Conferences, Purdue University Engn.* Extn. Ser. 325–330.

Schuhmacher H. & Schremmer F. (1970) Die Trichopteran des Odenwaldbaches 'Steinachs' und ihr okologischer Zeigerwert. *Int. Rev. ges. Hydrobiol.* **55**, 335–358.

Schwoerbel J. (1970) *Methods of Hydrobiology.* Pergamon Press, Oxford.

Surber E.W. (1953) Biological effects of pollution in Michigan waters. *Sew. industr. Wastes*, **25**, 79–86.

Thomas W.A., Goldstein G. & Wilcox W.H. (1973) *Biological Indicators of Environmental Quality.* Ann Arbor Science Publ. Inc.

Wilm J. (1970) Range of diversity index in benthic macro-invertebrate populations. *Wat. Poll. Control*, **2**, 221–224.

Woodiwiss F.S. (1964) A biological system of stream classification. *Chemistry and Industry*, 443–447.

Wurtz C.B. (1955) Stream biota and stream pollution. *Sew. industr. Wastes*, **27**, 1270–1278.