ASSESSING THE INFLUENCE OF ALTITUDE AND TEMPERATURE ON BIOLOGICAL MONITORING OF FRESHWATER QUALITY: A PRELIMINARY INVESTIGATION

JULIO A. CAMARGO
Centro de Ciencias Medioambientales, C.S.I.C., Serrano 115 dpdo., 28006 Madrid, Spain
and
DIEGO GARCIA DE JALON
Departamento de Ingeniería Forestal, E.T.S.I. de Montes, Universidad Politécnica, 28040 Madrid, Spain

(Received: September 1994; revised January 1995)

Abstract. The effect of altitude and water temperature on biomonitoring of freshwater quality was examined along an unpolluted area (36 km in length) of the upper Río Tajo (central Spain). The macrobenthic and fish communities were studied, and the Biological Monitoring Water Quality (BMWQ) method was applied. As expected, values of altitude and temperature respectively decreased and increased with increasing distance from the river source; these two physical parameters exhibited a negative and significant ($P<0.05$) correlation coefficient between them. However, despite evident changes in the functional structure of both aquatic communities along the study area, BMWQ scores were similar at all sampling sites. Pearson correlation coefficients between physical and biological parameters were not significant ($P>0.05$). The BMWQ index only exhibited significant (positive) correlation coefficients with macrobenthic and fish biomasses, indicating that freshwater quality could affect the biological production of fluvial ecosystems. It is concluded that biomonitoring of freshwater quality may be independent of the influence of altitude and water temperature at local spatial scales. Nonetheless, further investigations would be needed to clearly differentiate between the effects of anthropogenic and natural causes on biological monitoring at larger spatial scales.

1. Introduction

Biomonitoring of freshwater quality is meant to be caried out as a fundamental component of water-quality monitoring programs in developed countries (Cairns, 1989). Because it is usually impracticable to conduct biological monitoring on the entire aquatic metacommunity, water quality investigations tend to focus on particular communities (US EPA, 1993). According to Metcalfe (1989), a clear preference for using the macrobenthic community has emerged for the following major reasons: (1) benthic macroinvertebrates are ubiquitous, abundant, and relatively easy to collect, (2) they have life spans long enough to provide a record of environmental conditions, (3) they are relatively sedentary and thus are representative of local conditions, and (4) they are differentially sensitive to pollutants of various types and, accordingly, are capable of a graded response to a broad spectrum of kinds and degrees of stress. In addition, benthic macroinvertebrates are a critical pathway for the transport and utilization of energy in aquatic ecosystems (Newbold *et al.*, 1982).

Although there are several approaches to biomonitoring of freshwater quality based on the macrobenthic community, the most recent emphasis has been on developing the potential of biotic scores and indices (Metcalfe, 1989; Rosenberg and Resh, 1993). This methodology is derived from the observation that there is a progressive loss of pollution-intolerant macroinvertebrate taxonomic groups with increasing pollution load, assuming that macrobenthic tolerance to pollution (primarily organic) is the paramount factor affecting the value of biotic indices and scores. Familiar examples of biological monitoring methods are the Trent Biotic Index (TBI) (Woodiwiss, 1964), the Chandler Biotic Score (CBS) (Chandler, 1970), the Hilsenhoff Index (HI) (Hilsenhoff, 1977), and the Biological Monitoring Working Party (BMWP) score system (Armitage *et al.*, 1983). Logically, because macrobenthic taxonomy is geographically specific, no biotic score or index can work in every country in the world; modifications of original indices and scores are usually performed.

On the other hand, gradual changes in environmental factors (e.g. altitude, water temperature, water flow, food resources) along the longtitudinal profile of river systems exert a direct control on the population dynamics of benthic macronvertebrates and other aquatic organisms, resulting in characteristic biological communities within this ecological zonation (Illies and Botosaneanu, 1963; Hawkes, 1975). In this way, and under a synecological and holistic point of view, an unpolluted river can be regarded as a functional continuum (Vannote *et al.*, 1980; Minshall *et al.*, 1985). Hence, it is logical to think that the value of biotic indices and scores may be naturally affected by those environmental factors, at least at larger spatial scales.

Nevertheless, despite its importance, very little attention has been paid to this question of anthropogenic causes (e.g. organic pollution) versus natural causes (e.g. altitude, temperature). The difficulty seems to lie in the circumstance that, at the present time, it is arduous to find an extensive geographical territory with no human influence for analyzing the real effect of environmental factors on biological monitoring, Actually, it is generally assumed that the value of biotic scores and indices only depends upon pollution conditions (Rosenberg and Resh, 1993). In this respect, the present investigation examines the influence of altitude and water temperature on biomonitoring of freshwater quality through the spatial correlation between physical and biological parameters along an unpolluted area of one of the most important Iberian rivers. The macrobenthic and fish communities were studied to achieve this goal.

2. Material and Methods

2.1. Study Area and Sampling Sites

Field studies were conducted in a relatively unpolluted area (ca. 36 km in length) of the upper Río Tajo within the province of Guadalajara (central Spain) (Figure 1).

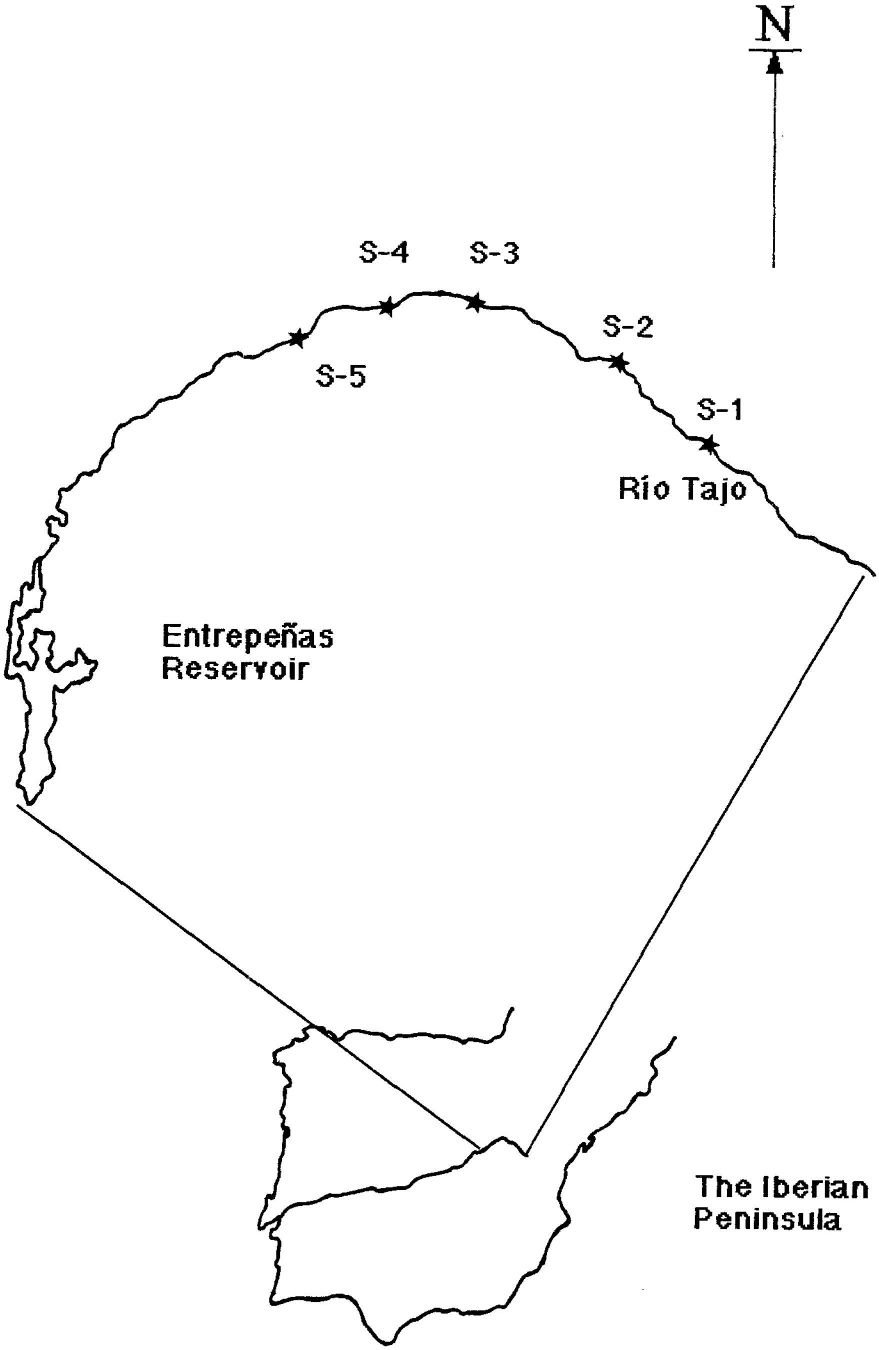

Fig. 1. General diagram of the study area in the Río Tajo showing the location of sampling sites (S-1, S-2, S-3, S-4 and S-5).

The watershed of this fluvial zone is mainly underlain by calcareous rocks (e.g. limestone) which induces the formation of hard waters with high ionic content. The natural flow regime is characterized by maximum flows during the winter season and minumum flows during the summer season. The cross-section of the river channel is more or less U-shape and varies from 7–17 m in width.

Five sampling sites were selected along the study area (Figure 1). S-1, S-2, S-3, S-4 and S-5 were respectively placed ca. 33, 42, 57, 62 and 69 km downriver from the river source. The river bottom was chiefly stony with boulders, pebbles and gravel.

2.2. BIOLOGICAL SURVEYS

Intensive biological surveys were undertaken during May, 1993. This month was chosen owing to the excellent representation of macroinvertebrate taxonomic groups along the study area and to the relative uniformity of water temperature at each sampling site.

The macrobenthic community was sampled using a Hess cylindrical sampler (Hellawell, 1986; ASTM, 1993) which enclosed a sampling area of 0.1 m^2 and was equipped with a 0.5 m net with a mesh size of 250 μm. Four riffle bottom replicates were collected at each station, being preserved in 4% formalin until laboratory analysis. Following identification and counting, quantitative samples were dried in an oven at 60 °C for 24 h to estimate biomass (dry weight).

The fish community was sampled using an electrofishing technique with a direct current of 440, 220 or 125 V and 1, 2 or 3 A (Garcia de Jalon *et al.*, 1993). At each sampling site, the study reach was delimited by nets and three successive captures at constant effort were accomplished. Following taxonomic identification, fishes were counted and weighed (alive).

2.3. THE BIOLOGICAL MONITORING WATER QUALITY METHOD

The Biological Monitoring Water Quality (BMWQ) score system (Table I) was used to determine freshwater quality in ecological terms. This biotic index is based on the British BMWP method (Armitage *et al.*, 1983), and has been adapted and applied for the biological monitoring of organic pollution and nutrient enrichment in rivers and streams of the Iberian Peninsula (Camargo, 1993, 1994). Its score values reflect the pollution tolerance of Iberian macroinvertebrate families; pollution-intolerant families exhibit high scores and pollution-tolerant families exhibit low scores. After macrobenthic samples have been analyzed, the total BMWQ score at a sampling site is estimated summing the individual scores of all families present, and the average BMWQ score is estimated by dividing this total by the number of families. Because the average BMWQ is less sensitive to sampling effort, seasonal change and marcobenthic diversity than the total BMWQ (Camargo, 1993, 1994), the average BMWQ score was applied in this investigation.

TABLE I

The Biological Monitoring Water Quality (BMWQ) score system. The foundations and limitations of this biotic index have been extensively discussed in Camargo (1993, 1994)

Macroinvertebrate families	Score
Perlidae Chloroperlidae Perlodidae Goeridae Lepidostomatidae Odontoceridae Thremmatidae Sericotosmatidae Beraeidae Helicopsychidae Blephariceridae	15
Taenioppterygidae Leuctridae Capniidae Ephemeridae Leptophlebiidae Heptageniidae Glossosomatidae Brachycentridae Leptoceridae Economidae Phryganeidae Thaumaleidae	13
Haplotaxidae Planariidae Bythinellidae Ephemerellidae Oligoneuriidae Sipholonuridae Cordulegasteridae Calopterygidae Limnephilidae Philopotamidae Calamoceratidae Aphelocheiridae Athericidae	12
Astacidae Gammaridae Nemouridae Polymitarcidae Libellulidae Aeschnidae Lestidae Psychomyiidae Rhyacophilidae Polycentropodidae Elmidae Hydraenidae	11
Dugesiidae Neritidae Potamanthidae Coenagrionidae Gomphidae Corduliidae Platycnemididae Hydroptilidae Helodidae Limoniidae	10
Ancylidae Unionidae Caenidae Hydropsychidae Gyrinidae Simuliidae Tabanidae Tupilidae	9
Dendrocoelidae Atyidae Bithyniidae Hydrobiidae Baetidae Curculionidae Haliplidae Corixidae Empididae Ceratopogonidae Dolichopodidae	8
Valvatidae Lymnaeidae Sialidae Hygrobiidae Dryopidae Dytiscidae Naucoridae Anthomyidae	7
Hirudidae Erpobdellidae Sphaeriidae Nepidae Notonectidae Psychodidae	6
Glossiphoniidae Planorbidae Hydrophilidae	5
Physidae Culicidae	4
Chironomidae Ephydridae	3
Oligochaeta (excluding *Haplotaxidae*)	2
Syrphidae	1

TABLE II

Mean ($n = 4$) densities (individuals per square meter) estimated for each macroinvertebrate taxonomic group at sampling stations (S-1, S-2, S-3, S-4 and S-5)

	S-1	S-2	S-3	S-4	S-5
Oligochaeta	172	241	17	42	6
Erpobdellidae	0	44	11	0	0
Ancylidae	0	91	0	0	0
Bythinellidae	0	58	0	0	0
Hydrobiidae	0	36	0	36	8
Lymnaeidae	0	66	0	3	0
Sphaeriidae	0	66	0	11	0
Baetidae	174	463	496	1136	216
Caenidae	166	3	17	23	80
Ephemerellidae	0	2830	701	28	72
Ephemeridae	33	11	3	3	25
Heptageniidae	0	22	3	22	8
Leptophlebiidae	0	10	15	0	0
Oligoneuriidae	0	8	5	0	0
Potamanthidae	0	0	0	0	0
Polymitarcidae	0	0	0	0	0
Leuctridae	0	50	3	17	0
Nemouridae	0	0	3	0	0
Perlidae	0	14	58	3	122
Perlodidae	14	28	0	0	0
Aeschnidae	0	0	28	3	0
Calopterygidae	0	0	0	3	0
Cordulegasteridae	0	3	0	0	3
Gomphidae	58	50	166	83	39
Dryopidae	0	0	3	0	33
Dytiscidae	0	6	3	0	3
Elmidae	87	736	809	1285	911
Helodidae	10	33	379	94	211
Beraeidae	0	0	0	0	0
Brachycentridae	0	0	0	0	119
Glossosomatidae	72	11	0	150	8
Hydropsychidae	39	197	33	122	39
Hydroptilidae	3	36	0	0	8
Lepidostomatidae	11	225	0	3	1119

TABLE II
(Continued)

	S-1	S-2	S-3	S-4	S-5
Limnephilidae	0	55	0	0	0
Philopotamidae	0	0	0	0	0
Polycentropodidae	6	8	14	0	3
Rhyacophilidae	8	6	8	0	5
Anthomyidae	0	0	0	0	0
Athericidae	0	9	0	11	16
Ceratopogonidae	44	3	6	3	6
Chironomidae	6	421	6	454	130
Dolichopodidae	0	8	0	0	0
Empididae	0	3	0	50	0
Limoniidae	186	0	0	0	0
Psychodidae	53	875	518	205	762
Simuliidae	44	8	83	80	69
Stratiomydae	3	208	72	0	0
Tabanidae	0	11	3	0	0
Tipulidae	0	3	0	3	0

TABLE III
Abundances (individuals per square meter) estimated for each fish species at sampling stations (S-1, S-2, S-3, S-4 and S-5)

	S-1	S-2	S-3	S-4	S-5
Barbus bocagei	0	0	0	0	0
Chondrostoma polylepis	0	0	0.002	0.004	0.029
Gobio gobio	0	0	0	0	0.012
Salmo trutta	0.018	0.095	0.042	0.097	0.113

3. Results

Values of altitude and temperature at the sampling sites are shown in Figure 2. While altitude values rationally decreased with increasing distance from the river source, temperature values increased. As a result, the Pearson correlation coefficient between both physical parameters was negative and significant (r=–0.924; P=0.025). Yet correlation coefficients between these two physical parameters and biological parameters were not significant (Table VI).

TABLE IV

Values of biological parameters and indices estimated for the macrobenthic community at each sampling site (S-1, S-2, S-3, S-4 and S-5). Total density and total biomass are respectively expressed in individuals per square meter and milligrams per square meter. BMWQ = Biological Monitoring Qater Quality score

	S-1	S-2	S-3	S-4	S-5
Number of taxonomic groups	20	38	27	26	26
Total density	1189	6890	3463	3873	4021
Total biomass	729	11567	4059	4643	7177
BMWQ	9.63	10.00	9.58	9.69	9.88

TABLE V

Values of biological parameters estimated for the fish community at each sampling site (S-1, S-2, S-3, S-4 and S-5). Total density and total biomass are respectively expressed in individuals per square meter and milligrams per square meter

	S-1	S-2	S-3	S-4	S-5
Number of species	1	1	2	2	4
Total density	0.018	0.095	0.044	0.101	0.159
Total biomass	0.789	11.870	3.997	1.625	8.414

TABLE VI

Pearson correlation matrix (n=5)

	Alt	Temp	Macr	DMacr	BMacr	BMWQ	Fish	DFish	BFish
Alt	1.000								
Temp	–0.924[a]	1.000							
Macr	0.148	0.134	1.000						
DMacr	–0.034	0.335	0.975[a]	1.000					
BMacr	–0.020	0.358	0.938[a]	0.975[a]	1.000				
BMWQ	0.118	0.269	0.755	0.808	0.907[a]	1.000			
Fish	–0.846	0.873	–0.187	–0.004	0.104	0.149	1.000		
DFish	–0.623	0.870	0.344	0.535	0.624	0.674	0.764	1.000	
BFish	0.048	0.283	0.848	0.862	0.944[a]	0.907[a]	0.181	0.576	1.000

Alt = altitude; Temp = temperature; Macr = number of macroinvertebrate taxonomic groups; DMacr = total density for the macrobenthic community; BMacr = total biomass for the macrobenthic community; BMWQ = Biological Monitoring Water Quality score; Fish = number of fish species; DFish = total density for the fish community; BFish = total biomass for the fish community; [a] = P<0.05.

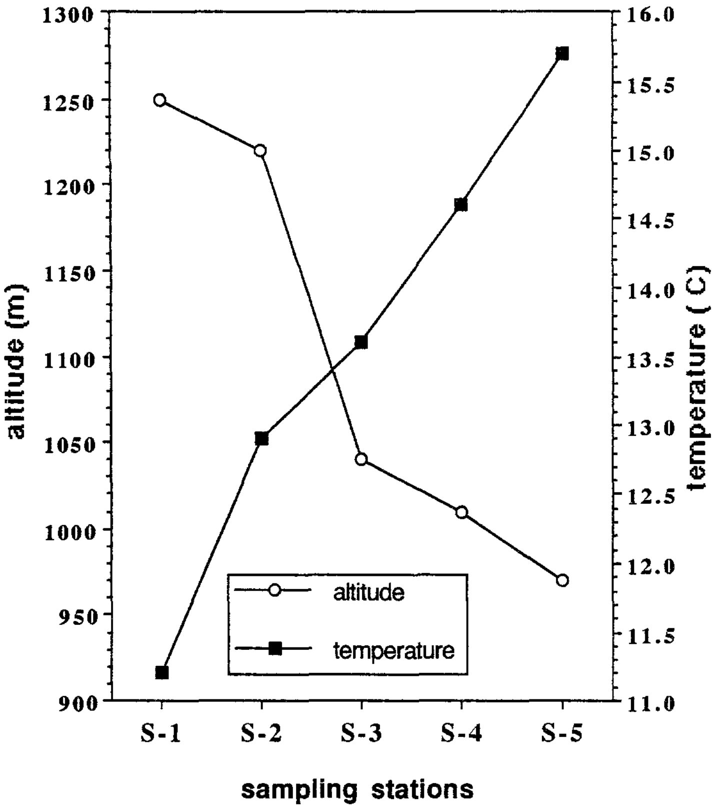

Fig. 2. Spatial variation of altitude (m) and water temperature (°C) along the study area. Temperature values were measured by means of a mercury thermometer in accordance with APHA (1989).

Densities of macroinvertebrate taxonomic groups (families, primarily) at each station are presented in Table II. Aquatic insects dominated the macrobenthic community, ephemeropterans (*Baetidae* and *Ephemerellidae*), coleopterans (*Elmidae*), trichopterans (*Lepidostomatidae*) and dipterans (*Phychodidae*) being the most abundant macroinvertebrates. Besides the number of taxonomic groups, total density and total biomass exhibited parallel variations along the study area (Table IV) and, accordingly, had positive and significant (P<0.05) correlation coefficients between them (Table VI).

Abundances of fish species at each station are presented in Table III. The salmonid *Salmo trutta* was the most abundant species at all sampling sites, the number of fish species tending to increase with distance from the river source. However, total density and total biomass exhibited different downstream spatial variations (Table V). As a result, Pearson correlation coefficients between the number of fish species, total density and total biomass were not significant (Table VI).

BMWQ scores were relatively similar at all sampling sites (Table IV). Consequently, Pearson correlation coefficients between BMWQ index and physical parameters were low and not significant (Table VI). Furthermore, BMWQ scores only exhibited significant ($P<0.05$) correlation coefficients with total biomass of macrobenthic and fish communities (Table VI).

4. Discussion

The River Continuum Concept (RCC) (Vannote *et al.*, 1989; Minshall *et al.*, 1985) predicts downriver modifications in the abundance of benthic macroinvertebrates as environmental factors change along the longtitudinal profile of river systems. According to the RCC, the functional diversity of macrobenthic communities peaks in the midreaches of a river. Even so, ecological zonation of unpolluted rivers (Illies and Botpsaneanu, 1963; Hawkes, 1975) shows that the number of fish species tends to increase with distance from the river source, salmonids being primarily abundant in upper reaches (*rithron*) and cyprinids being dominant in lower reaches (*potamon*).

In this investigation, alterations in the macrobenthic and fish communities along the study area (Table II–V) reflect the action of some environmental factors. However because Pearson correlation coefficients between physical and biological parameters were not significant (Table VI), it is evident that other environmental factors (e.g. water flow, food resources) rather than or in addition to altitude and temperature would determine the spatial distribution of fishes and benthic macroinvertebrates in the upper Río Tajo. Moreover, because *Salmo trutta* was the most abundant fish species at all sampling sites, it is not surprising that freshwater quality in ecological terms (BMWQ method) exhibits high and similar values along the study area. Brown trout is very sensitive to anthropogenic pollution, its abundance markedly decreasing with increasing pollution load (Alabaster and Lloyd, 1980; Hellawell, 1986).

On the other hand, the positive and significant correlation between macrobenthic biomass and fish biomass (Table VI) should be viewed as a reasonable outcome of the fact that benthic macroinvertebrates constitute a basic food resource for *Barbus bacagei, Gobio gobio* and *Salmo trutta.* Thus, in the absence of anthropogenic pollution, freshwater quality could inderectly influence fish production through macrobenthic production in fluvial ecosystems. This would explain the positive and significant correlation between BMWQ index and total biomasses of fish and macrobenthic communities (Table I).

It is concluded that biomonitoring of freshwater quality based on benthic macroinvertebrates, which integrates environmental factors over time and reflects the cumulative impact of multiple stresses on the macrobenthic community, may be independent of the influence of altitude and water temperature at relatively local spatial scales. Consequently, both physicochemical and biological surveys should be conducted during water pollution studies in order to provide the maximum information for a satisfactory protection of river systems. Yet, because alitude, temperature and other environmental factors can affect the value of biotic indices at larger spatial scales, further investigations would be needed to differentiate clearly between the effects of anthropogenic causes and natural causes for the improvement of regional water-quality monitoring programs in developed countries.

Acknowledgements

The authors thank M. Gonzalez del Tanago for valuable comments on an early draft of this manuscript. In addidion, we are grateful to M. Mayo, F. Hervella, A. Mingo, J. Rodriguez and P. Brotons for their assistance in biological surveys. The Department of Forestry Engineering (E.T.S.I. de Montes, Universidad Politécnica de Madrid, Spain) provided logistical support during this investigation.

References

Alabaster, J. S. and Lloyd, R.: 1980, *Water Quality Criteria for Freswater Fish*, Butterworths, London.

APHA: 1989, *Standard Methods for the Examination of Water and Wastewater*, 17th ed, APHA–AWWA–WPCF, Washington, DC.

Armitage, P. D., Moss, D., Wright, J. F. and Furse, M. T.: 1983, 'The Performance of a New Biological Water Quality Score System Based on Macroinvertebrates over a Wide Range of Unpolluted Running-Waters Sites', *Water Res.* **17**, 333–347.

ASTM: 1993, *Aquatic Toxicology and Hazard Evaluation*, American Society for Testing and Materials, Philadelphia.

Cairns, J. Jr.: 1989, 'Biological Monitoring of Water Quality', in: Ward, R. C., Loftis, J. C. and McBride, G. B. (eds.), *Design of Water Quality Information Systems. Proceedings of an International Symposium*, Colorado Water Resources Research Institute, Fort Collins (USA), pp. 338–346.

Camargo, J. A.: 1993, 'Macrobenthic Surveys as a Valuable Tool for Assessing Freshwater Quality in the Iberian Peninsula', *Environ. Monitor. Assess.* **24**, 71–90.

Camargo, J. A.: 1994, 'The Importance of Biological Monitoring for the Ecological Risk Assessment of Freshwater Pollution: A Case Study', *Environ. Int.* **20**, 229–238.

Chandler, J. R.: 1970, 'A Biological Approach to Water Quality Management', *Water Pollut. Control* **69**, 415–421.

Garcia de Jalon, D., Mayo, M., Hervella, F., Barcelo, E. and Fernandez, T.: 1993, *Principios y Técnicas de Gestión de la Pesca en Aguas Continentales*, Ediciones Mundi-Prensa, Madrid.

Hawkes, H. A.: 1975, 'River Zonation and Classification', in: Whitton, B. A. (ed.), *River Ecology*, Blackwell Scientific Publications, Oxford, pp. 313–374.

Hellawell, J. M.: 1986, *Biological Indicators of Freshwater Pollution and Environmental Management*, Elsevier Applied Science Publishers, London.

Hilsenhoff, W. L.: 1977, *Use of Arthropods to Evaluate Water Quality of Streams*, Technical Bulletin No. 100, U.S. Department of Nature Research.

Illies, and Botosaneanu, L.: 1963, 'Problèmes et Méthodes de la Classification et de la Zonation Ecologique des Eaux Courantes, Considerées surtout du Point de Vue Faunistique', *Verh. Int. Verein. Limnol.* **12**, 1–57.

Metcalfe, J. R.: 1989, 'Biological Water Quality Assessment of Running Water Based on Macroinvertebrate Communities: History and Present States in Europe', *Environ. Pollut.* **60**, 101–139.

Minshall, G. W., Cummins, K. W., Petersen, R. C., Cushinh, C. E., Bruns, D. A., Sedell, J. R. and Vannote, R. L.: 1985, 'Developments in Stream Ecosystem Theory', *Can. J. Fish. Aquat. Sci.* **42**, 1045–1055.

Newbold, J. D., O'Neill, R. V., Elwood, J. W. and Van Winkle, W.: 1982, 'Nutrient Spiralling in Streams; Implications for Nutrient Limitation and Invertebrate Activity', *Am. Nat.* **120**, 628–652.

Rosenberg, D. M. and Resh, V. H. (eds.): 1993, *Feshwater Biomonitoring and Benthic Macroinvertebrates*, Chapman & Hall, New York.

US EPA: 1993, *A Review of Ecological Assessment Case Studies from a Risk Assessment Perspective*, 630/R-92/005, EPA, Washington, DC.

Vannote, R. L., Minshall, G. W., Cummins, K. W., Sedell, J. R. and Cushing, C. E.: 1980, 'The River Continuum Concept', *Can. J. Fish. Aquat. Sci.* **37**, 130–137.

Woodiwiss, F. S.: 1964, 'The Biological System of Stream Classification Used by the Trent River Board', *Chem. Ind.* **11**, 443–447.