Acta Hydrobiol., 42 (2000), 3/4, 187–206. Cracow, December 2000

The use of benthic macroinvertebrates in the biomonitoring of river water quality – how do we interpret faunistic data?*

Andrzej KOWNACKI

Karol Starmach Institute of Freshwater Biology, Polish Academy of Sciences, ul. Sławkowska 17, 31-016 Kraków, Poland

(Received 25 November 1999, Accepted 24 November 2000)

Abstract – The work was carried out with the aim of determining opportunities for faunistic data to be employed in the assessment of the quality of rivers on the basis of indicator organisms (the saprobic system and species scales), as well as the characteristics (abundance, biodiversity, and dominance structure) of communities or assemblages. A 5-point scale of assessment based on the abundance and structure of invertebrate communities is also proposed. Attention is paid to the difficulties noted in creating a unified, universal system for the biomonitoring of rivers across the whole country, as well as to the need for a series of ecological factors to be taken account of, most notably the zonal distribution of zoocoenoses along the course of a river, habitats, and the seasons of the year.

Key words: river, pollution, biomonitoring, invertebrate communities, benthos.

1. Introduction

The current assessment of the quality of surface waters in Poland is mainly achieved on the basis of physico-chemical parameters (Ordinance 1991). However, there is an ever more prevalent opinion that Poland should fall into line with Western European countries in accepting biomonitoring, i.e. the use of biological parameters, as a further basis upon which to assess water quality.

From among the many definitions of biomonitoring, the one regarded as best by Rosenberg and Resh (1992) is that which holds that "Biological monitoring can be defined as the systematic use of biological response to evaluate changes in the environment with the intent of using this information in a quality control program. These changes are often due to anthropogenic sources." However, in relation to flowing waters, the proposed definition fails to encompass the most important element allowing the superiority of biological monitoring to be recognised, i.e. time. It is widely known that physico-chemical research allows for a river's quality to be determined at a given moment, while reference to a biocoenosis allows the changes in water quality ongoing over a longer period of time to be determined. For this reason, there is a need to adopt a definition for rivers which has it that "Biological

* The work was carried out within the framework of the State Committee for Scientific Research (KBN) research project No 6 PO4G 036 16.

monitoring may be defined as the systematic use of biological indicators (species, populations, taxocoens, and communities) in determining changes in the quality of the environment ongoing in a river over a longer period of time".

The aim of the present work has thus been to consider the different possibilities for interpreting faunistic data and to put forward proposals for their use in assessing river quality.

2. Ecological characteristics of rivers

In carrying out proceeding with biomonitoring studies it is important to recall several basic facts concerning the ecology of rivers themselves.

1. The dominant element of biocoenoses are the communities of plants and animals living on the bottom – i.e. the benthos (it is the zoobenthos that will be under consideration here). Although an important element in lakes, plankton does not play a more major role in small and medium-sized rivers. Only in the lower courses of large rivers may there be a development of the so-called potamoplankton, comprising species that spend their whole lives in the water. However, there is no plankton community specific to rivers that would be derived from species not present in still waters. The water of rivers is in turn characterized by the phenomenon of invertebrate drift, in which animals or higher plants are detached at random from the bottom and carried for a while by the current. Some species of the bottom fauna may even take advantage of this means to migrate at certain times. To sum up, the composition of the carried fauna is some reflection of the community developing on the bottom, but differs from it in terms of both abundance and structure, and may even change during the course of a day (Waters 1962, Brittain and Eikeland 1988).

2. Zoobenthic communities change along a watercourse between its source and its mouth. There is now extensive literature on the zonal distribution of fauna community and the typology of rivers. This is summarised in the works by Illies and Botosaneanu (1963), Hynes (1972), Vannote *et al.* (1980), Botosaneanu (1988), and Ward (1992), and supplemented by work on high-mountain streams from Steffan (1971) and Kownacka and Kowanacki (1972).

3. Communities of zoobenthos vary from one river zone to another. In the section of river studied, it was possible to identify fauna community of sites in the current and in calm waters, as well as those developing on stony, sandy, and alluvial substrata. Information on this is contained in generally accessible hydrobiology handbooks (Starmach et al. 1976), handbooks on rivers (Hynes 1972, Whitton 1984), and studies on aquatic invertebrates (Thienemann 1954, Ward 1992).

4. Communities of zoobenthos change in the course of the year, in terms of both abundance and structure, as well as with the replacement of given species by others as the seasons pass. The literature on this is again very extensive and summed up in handbook studies.

5. The least-documented phenomena are the differences in zoobenthos between different drainage basins. However, a review of the literature on various rivers and streams makes it very clear that each basin has a rather different zoobenthos, mainly in association with geological structure, the nature of the soil, and the vegetation cover in the drainage basin. This variability often finds its reflection in the nomenclature of rivers. Thus, for example, the White and Black Vistula rivers have their different invertebrate communities (Wróbel 1998).

Besides these general factors affecting the development of zoobenthos in running waters, a series of local factors should also be taken into account. These include ecological catastrophes (floods and droughts), as well as changes in the vegetation cover of a basin (through forest cutting, changes in cultivation, etc.). Only by constantly bearing in mind that a river is not a uniform ecosystem can one even begin biomonitoring research.

3. Biomonitoring

3.1. Indicator organisms

The most widespread system is that of "indicator organisms" which may be species or populations. "The ideal indicator organism" would meet the following criteria (after Rosenberg and Resch 1992 – modified). It should:

1. have a narrow and specific range of ecological requirements (ubiquitous organisms are of little use);
2. have a wide geographical range (endemic species are not very suitable);
3. be present in the environment in abundance (as dominants or sub-dominants);
4. have a long life cycle (preferably annual) or several generations following on from one another in the course of the year;
5. be easy to identify – even by non-specialists – and characterized by a limited degree of morphological and genetic variability.

A familiarity with the biology and physiology of the "indicator organism" is desirable. If the system assessing the pollution of rivers on the basis of "indicator organisms" is to serve its purpose, then there must be a possibility for it to be encompassed by unambiguous legal standards.

3.1.1. The saprobic system

The oldest present-day system for the assessment of water quality in rivers is the saprobic one proposed by Kolkwitz and Marson (1909). Those authors made a distinction between four zones: oligosaprobic (clean waters), beta-mesosaprobic (slightly polluted), alpha-mesosprobic (polluted), and polysaprobic (highly polluted). Ascribed to these zones are a series of indicative organisms that include macroinvertebrates. The system has undergone many modifications as overall knowledge on the subject has developed (Sládeček 1973), or as local peculiarities have come to be understood (Margreiter-Kownacka *et al.* 1984). Besides changes in the lists of indicator species, a series of additional zones has been introduced (Sládeček 1973, Turoboyski 1979), e.g. the hypersaprobic zone, in which untreated sewage floats and there is a virtual absence of organisms other than bacteria and colour-less flagellates, as well as the catharobic zone, which is characterized by a lack of organic compounds and a low level of mineralization, and which is inhabited by organisms of clean water only. The system was adapted for Polish conditions by Turoboyski (1979) (Table I). It should be stressed that Kolkwitz and Marsson (1909) had already quite often given information to the effect that the species they mentioned could occur in a neighbouring zone. This is indicated more clearly by Sládeček (1973). Each indicator species is assigned 10 points, which are respectively divided among the different zones. Among the 253 zoobenthic taxa mentioned in the Sládeček's list, only a few are ascribed to a single zone (10 and 9 points) (Table II). The remaining species have a much wider range. However, there is even no unanimity as regards the range of occurrence of the "model" zoobenthic taxa distinguishing different zones in a river, i.e. *Tubifex*, *Chironomus*, and *Asellus aquaticus* (L.) (Fig. 1).

Table I. The Polish system of assessing pollution of waters on the basis of zoobenthic indicator organisms (after Turoboyski 1979)

Zones	Indicatory organisms
Polysaprobic	OLIGOCHAETA
	Tubifex tubifex (O.F. Müller)
	DIPTERA (Syrphidae)
	Eristalis tenax (L.)
Alpha-mesosaprobic	BIVALVIA
	Shpaerium corneum (L.)
	ISOPODA
	Asellus aquaticus (L.)
	TRICHOPTERA
	Cheumatopsyche lepida (Pictet) [= *Hydropsyche lepida* Pictet]
	DIPTERA (Chironomidae)
	Chironomus sp. [= *Ch.* gr. *thummi*]
Beta-mesosaprobic	GASTROPODA
	Lymnaea stagnalis (L.)
	- *auricularia* (L.)
	- *peregra* (O.F. Müller) [= *L. ovata* (Drap.)]
	Ancylus fluviatilis (O.F. Müller)
	Planorbis corneus (L.) [= *Coretus corneus* (L.)]
	OLIGOCHAETA
	Stylaria lacustris (L.)
	HIRUDINEA
	Glossiphonia complanata (L.)
	Erpobdella octoculata (L.)
	EPHEMEROPTERA
	Leptophlebia vespertina (L.)
	Habrophlebia lauta Eaton
Oligosaprobic	TURBELLARIA
	Crenobia alpina (Dana) [= *Planaria alpina* Dana]
	Dugesia gonocephala Duges
	Dandrocoelum lacteum O.F. Müller
	GASTROPODA
	Viviparus viviparus (L.)
	Dreissena polymorpha (Pallas)
	AMPHIPODA
	Gammarus pulex (L.) [= *Rivulogammarus pulex* (L.)]
	EPHEMEROPTERA
	Potamanthus luteus (L.)
	Heptagenia sulfurea (O.F. Müller)
	Electrogena lateralis (Curtis) [= *Ecdyonurus lateralis* (Curtis)]
	Ecdyonurus fluminum (Pictet)[a]
	Epeorus sylvicola (Pictet) [= *E. assimilis* Eaton]
	Rhithrogena semicolorata (Curtis)[b]
	Oligoneuriella rhenana (Imhoff)
	Baetis (?) *bioculatus* (L.)
	- *rhodani* (Pictet)
	Cloeon dopterum (L.)

Table I. *continued*

Zones	Indicatory organisms
	Habroleptoides modesta (Hagen)[c]
	Ephemerella ignita Poda
	PLECOPTERA
	Perla bipunctata Pictet
	Brachyptera seticornis (Klapalek) [= *Taeniopteryx seticornis* Klapalek]
	TRICHOPTERA
	Rhyacophila nubila (Zetterstedt)
	- *vulgaris* Pictet
	Phryganea grandis (L.)

[a] occurrence in Poland dubious, records of this species concern *E. dispar* (Curtis) and/or *E. aurantiacus* (Burmeister)
[b] larvae of several *Rhithrogena* species are difficult to distinguish
[c] occurrence in Poland dubious, records of this species concern *H. confusa* Sartori et Jacob

The saprobic system was mainly founded on experience gained with lowland rivers polluted by organic effluents (Table III). In mountain rivers, the influx of even greater amounts of such wastewater does not bring about such drastic changes as in lowland rivers. Mountain brooks and streams always have well-

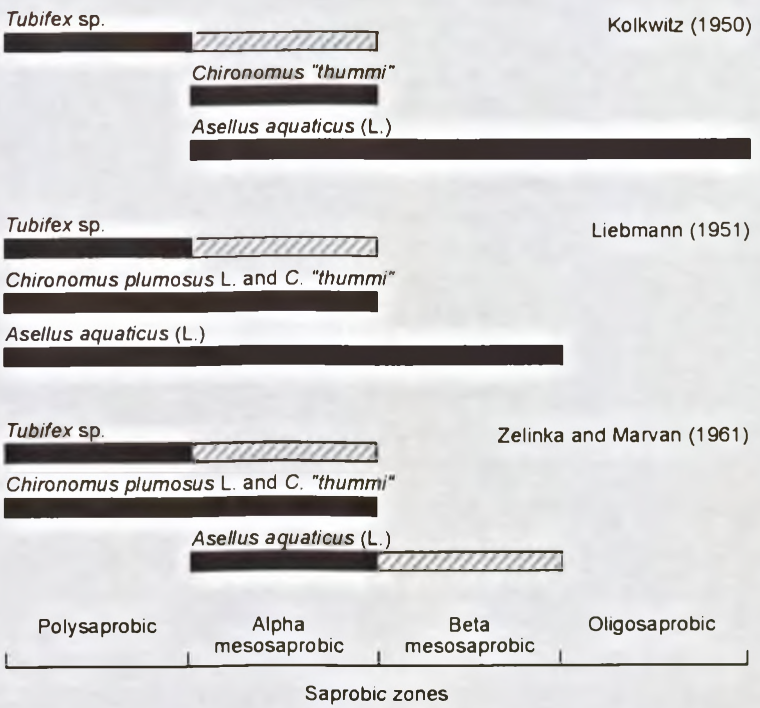


Fig. 1. Distribution of "model" indicator organisms in various saprobic zones, according to different authors (after Moller Pillot 1971, modified).

Table II. Zoobenthic indicator organisms with a narrow and specific scope of ecological requirements, with index value of 10 and 9, typical of particular saprobic zones (selected from among 253 zoobenthic taxa in the saprobic list by Sládeček 1973).

Zones	Indicatory organisms
Xenosaprobic	TURBELLARIA
	Crenobia alpina (Dana)
	Polycelis felina (Dalyell) [= *P. cornuta* (Johnson)]
	MALACOSTRACA
	Niphargus sp. div.
	GASTROPODA
	Bithinella austriaca Frau
	HYDRACARINA
	Hygrobates foreli (Lebert)
	EPHEMEROPTERA
	Ameletus inopinatus Eaton
	Rhithrogena hybrida (Eaton)
	- *loyolaea* Navas [= *R. tatrica* Zelinka]
	PLECOPTERA
	Amphinemura borealis (Morton)
	Arcynopteryx compacta McLach.
	Diura bicaudata (L.)
	Leuctra rosinae Kempny
	Protonemura meyeri Pictet
	- *nimborella* Mosely
	ODONATA
	Agrion virgo (L.)
	TRICHOPTERA
	Apatania fimbriata (Pictet)
	Odontocerum albicorne (Scop.)
	DIPTERA
	Liponeura sp. div.
Oligosaprobic	BIVALVIA
	Margaritana margaritifera (L.)
	PLECOPTERA
	Protonemura praecox (Morton)
	TRICHOPTERA
	Molanna angustata Curtis
Alpha-mesosaprobic	OLIGOCHAETA
	Euilyodrilus moldaviensis Vejd. et Mrazek
Polysaprobic	DIPTERA
	Eristalomyia tenax (L.)

Table III. Relation between categories of indicatory organisms and water purity zones (after Starmach et al. 1976): ++++ – exclusive occurrence, +++ – mass occurrence, ++ – abundant, + – rare.

Zones	Categories of organisms			
	Saprobiontic	Saprophilic	Saproxenic	Saprophobic
Polysaprobic	++++	+		
Alpha-mesosaprobic	+	+++	+	
Beta-mesosaprobic	+ (or absent)	++	+	
Oligosaprobic		+	++++	+
Catharobic			+	++++

-oxygenated water, thanks to the mechanism of mixing. The fast current ensures that greater amounts of organic matter do not settle on the bottom, but rather are carried downstream, or else accumulate in places with a weaker current or under stones. Only in these habitats can organisms indicative of polluted waters be found. In contrast, areas in the current, even if highly-polluted, can support organisms widely regarded as requiring clean water (Table IV).

Table IV. Sanitary classification of mountain and lowland rivers (after Sadovskij 1940, modified).

Zones	Oxygen concentration	Categories of indicatory organisms	Examples of rivers
Polysaprobic	High	Saproxenic + saprophilic	Heavily polluted mountain rivers
	Low	Saprobiontic	Heavily polluted lowland rivers
Mesosaprobic	High	Saprophobic + saproxenic	Slightly polluted mountain rivers
	Low	Saprophilic	Slightly polluted lowland rivers
Oligosaprobic	High	Saprophobic	Clean reaches of mountain and lowland rivers
	Low	?	Groundwaters, spring outflows

A further problem with the application of the saprobic system is that of the proper determination of taxa. In many cases, correct identification of species within certain genera even possess problems for specialists in systematics, to say nothing of those who make routine analysis in environmental monitoring centres. Examples here may be mayflies of the genera *Heptagenia*, *Ecdyonurus*, *Rhithrogena*, or *Baetis* and caddisflies of the genus *Rhyacophila*, in the case of the oligosaprobic zone, or the bivalve *Sphaerium corneum* (L.) and the caddisfly *Hydropsyche* in the case of the alpha-mesosaprobic zone, as given in the list of indicator organisms after Turoboyski (1979). Species within these genera have similar body shape and differ only in small anatomical particulars, despite of having diverse ecological requirements (Sowa 1975, Szczęsny 1986, Piechocki and Dyduch-Falniowska 1993).

In summing up, it should be stated that – thanks to more than 90 years of experience gained by many researchers in various countries – the saprobic system has come to be the best worked-out method, and one which supplies a great deal of information of an ecological and practical nature. Furthermore, the system is capable of being encapsulated within relatively unambiguous legal norms. Equally, however, a series of deficiencies must be acknowledged. In the course of routine study, the necessity of being familiar with a great number (in the case of Sládeček 1973, as many as 250) of macroinvertebrate indicator organisms representative of many systematic groups, whose taxonomy is usually very difficult, may lead to the erroneous designation of different species, and thus to the drawing of wrong conclusions. The method also possess problems of interpretation as comparisons are made between different types of river (such as those of mountains and lowlands) and different types of wastewater (e.g. industrial and organic effluents).

3.1.2. "The Scale of sensitivity of species"

A variant saprobic system might be the so-called "scale of sensitivity of species". Two types of such scales may be distinguished here. The first "scale of sensitivity of species" is based on a familiarity with a defined systematic group. Such a scale for the assessment of water quality in French rivers based on molluscs was devised by Mouthon (1996) and Mouthon and Charvet (1999). This scale correlated the occurrence of molluscs in rivers with the amount of dissolved oxygen, BOD_5, and concentrations of ammonia, nitrites, nitrates, and phosphates which were shown as indicative of pollution. The scale takes into account 47 species, divided into 13 groups of differing sensitivity to pollution. The most tolerant of the species is *Physella acuta* Draparnaud (in Group 1). Groups 2–5 inclusive embrace species resistant to organic pollutants, including *Pisidium casertanum* (Poli), *P. personatum* Malm., *Valvata cristata* O.F. Müller, *Lymnaea peregra* O.F. Müller, *L. auricularia*. (L.), *L. palustris* O.F. Müller, and *Ancyclus fluviatilis* O.F. Müller. The species considered sensitive to pollution include *Unio pictorum* (L.), *U. crassus* Philipsson, *U. tumidus*. Philipsson, *Anodonta anatina* (L.), *A. cygnea* (L.), and *Lymnaea stagnalis* (L.) (in Groups 9–12 inclusive) – and are characteristic of large rivers (the potamon zone). The scale coincides with that from earlier work carried out in America (Hart and Fuller 1974), from which it was concluded that the Unionidae are the first molluscs to be eliminated by pollution, while the Sphaeriidae develop well with moderate levels of pollution and the Physidae are the most tolerant species. The development of the "mollusc scale" in Polish conditions might be very appropriate, since the Polish keys to snails (Piechocki 1979) and bivalves (Piechocki and Dyduch-Falniowska 1993) make their correct identification possible. Equally, other systematic groups may be used in the formation of this kind of scale (Hart and Fuller 1974). Similar scales based on a familiarity with the Chironomidae were used in assessing the quality of lakes (Saether 1975, 1979), but they may also be used in checking the water quality of large lowland rivers. A still more simplified scale was applied by Wiederholm (1980) in assessing the monitoring of lakes using the Benthic Quality Index (BQI). The basis for this scale is provided by indicative species of Chironomidae or Oligochaeta (Table V).

A "scale of sensitivity of species" based on the knowledge of a defined systematic group provides a great deal of ecological information, and because the determinations are usually made by specialists, no reservations are aroused. Specialists are also able to better interpretation the results obtained. Furthermore, a scale of this kind can be presented in the form of norms. However, a disadvantage of the system is the fact that the non-specialists will have great difficulties in

Table V. The k_i values for Benthic Quality Index (BQI = (n_i k_i)/N, where: N – total number of indicatory species, n_i – number of individuals of ith species; after Wiederholm 1980).

k_i	OLIGOCHAETA	CHIRONOMIDAE
5		*Heterotrissocladius subpilosus* Brun
4	*Stylodrilus heringianus* Clap *Rhynchelmis limnosella* Hoffm.	*Micropsectra* spp *Paracladopelma* spp.
3	*Peloscolex ferox* (Eisen)	*Phaenopsectra coracina* *Stictochironomus rosenschoeldi* (Zett.)
2	*Potamothrix hammoniensis* (Mich.)	*Chironomus anthracinus* Mich.
1	*Limnodrilus hoffmeisteri* Clap.	*Chironomus plumosus* L.
0*		

* above-mentioned indicatory species are absent

correctly identifying all or a few systematic groups (exceptions might be e.g., molluscs). A further problem concerns the limitations of such a scale – for example, the way in which the mayflies are rapidly eliminated by relatively small loads of organic pollutants (Kownacki 1980).

A scale of a second type is that comprising several species from different systematic groups of well-known resistance to a defined factor. Such scales have been established to assess the degree of acidification of water (Fjellheim and Raddum 1990) (Table VI), the amounts of heavy metals therein, or the amounts of another factor exerting a destructive effect on the aquatic environment. An advantage of this system is the relative ease with which it can be used, a disadvantage being the fact that every factor requires its own "species scale". As scales of this type have only begun relatively recently to appear, it is not yet known how they may be modified by the physiological and biochemical processes of organisms.

Table VI. An example of the "scale of sensitivity of species" used in the monitoring of acidification (after Fjellheim and Raddum 1990).

Species	pH			
	>5.5	5.0–5.5	4.7–5.0	<4.7
Lymnea peregra (O. F. Müller)	●			
Gammarus lacustris G.O. Sars	●			
Baetis rhodani (Pictet)	●	●		
Siphlonurus aestivalis (Eaton)	●	●		
Caenis horaria (L.)	●	●		
Pisidium spp.	●	●	●	
Heptagenia fuscogrisea (Retzius)	●	●	●	●
Nemoura cinerea (Retzius)	●	●	●	●
Cyrnus flavidus McLachland	●	●	●	●

3.2. The benthic macroinvertebrate community

It should be recalled that different species and populations in nature do not live in isolation but are a part of communities or biocoenoses living in the given environment (e.g. river), habitat (e.g. current, area of still water), or even microhabitat (the surface or underneath parts of the same stone in a stream). To be considered below is the benthic macroinvertebrate community or part of the biocoenosis. The features characterizing the macroinvertebrate community and appropriate monitoring are: (1) the density (ind. m^{-2}) of all organisms; (2) the biodiversity, and especially species richness in the given area; and (3) dominance (not all species in a community are equally important in determining its nature, and just a few species usually occur very abundantly as dominants, while 10–20 are sub-dominants, and the remaining tens or hundreds are encountered only sporadically and termed adominants).

3.2.1. Faunal density

Faunal density changes in relation both to the section of a river studied and the season of the year, as well as the effect of incoming wastewater. Influxes of organic effluents are particularly likely to ensure a dramatic initial rise in abundance, before the crossing of a certain threshold concentration leads to the complete disappearance of the macroinvertebrate fauna, or else to a situation in which only single specimens of species adapted to living in concentrated waste waters are encountered (such as flies of the genera *Eristalis* and *Psychoda*, which obtain oxygen from the air, rather than that dissolved in water). Using a certain routine, an assessment based on abundance permits the rapid determination of the state of pollution of a defined river (Figs 2 and 3). Unfortunately, problems arise

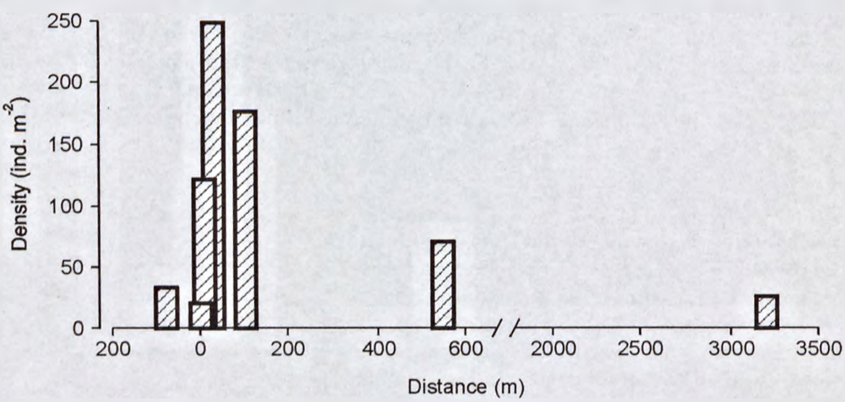
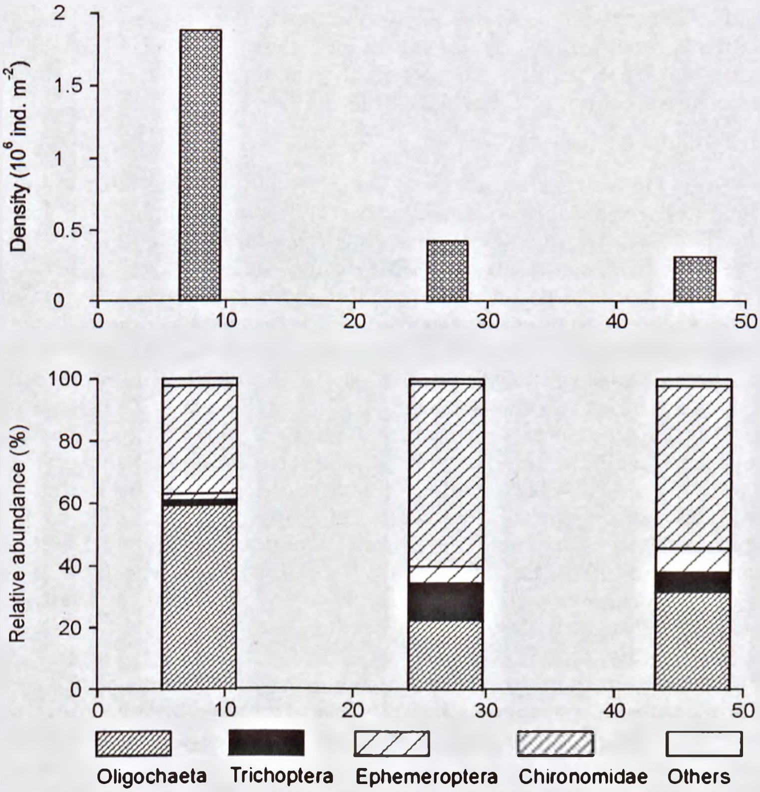


Fig. 2. Changes in the abundance of fauna in the Rybi Potok stream below the sewage discharge at the Morskie Oko lake in the Tatra Mountains (after Kownacki 1977).

as efforts are made to embrace the assessment by legal norms. Which figures are to be ascribed to given water quality classes? In the Vistula downstream of the Łączany weir, the abundance of fauna varies from 7000 to 2,056,000 ind. m^{-2}, with such changes following a highly irregular course (Dumnicka and Kownacki 1988). Hydrology also affects the abundance of the fauna, being very low after a flood, in spite of the amounts of nitrogen and phosphorus compounds being higher owing to



Dominant taxa		Dominance (%)	
Nais barbata O.F. Müll.	29	2	2
Nais elinguis O.F. Müll.	11	4	11
Cricotopus (agr.)	11	19	10
Nais bretscheri Michaelsen	11	8	7
Orthocladius gr. *rivicola*	2	12	11
Total number of taxa	96	119	119

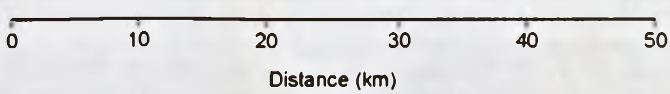


Fig. 3. Effect of the discharge of wastewater from Nowy Targ on the communities of benthic macroinvertebrates in the River Dunajec (after Szczęsny 1995, modified).

runoff. Still greater problems are posed by the assessment of mixed industrial and municipal wastewaters. It may turn out that an increase in the load of organic matter does not result from any raising of faunal abundance, owing to the toxic action of co-occurring industrial effluents.

3.2.2. Biodiversity

While the concept of biological diversity has by now been known in ecology for a long time, it is only in recent years that it has made itself known world wide (Gliwicz 1992, Głowaciński 1994, Hawksworth 1996, Hilbricht-Ilkowska 1998) as a basic element of the idea of nature conservation.

Determinations of the state of water quality in rivers may make use of species richness. It is accepted that increasing anthropogenic impact leads to a reduction in the number of species in a given ecosystem or region. This is justified, and a series of examples may be provided. In the 1980s, the most polluted section of the Vistula between Oświęcim and Kraków yielded only 40 taxa of zoobenthos, with the *Oligochaeta*. being the dominant group (Dumnicka and Kownacki 1988). The species of caddisfly, mayfly, and stonefly that were still to be encountered in the 1940s (Starmach 1948), had completely disappeared from this stretch. Similar examples come from the long-term study of the River Dunajec along the stretch between Nowy Targ and the Pieniny Mountains (Dratnal and Szczęsny 1965, Dratnal *et al.* 1979, Szczęsny 1995). In the course of the last 30 years, there has been a several-fold increase in the pollution of this section of the Dunajec (Kownacki and Starmach 1989). The effect has been to drastically reduce the number of species in most faunal groups.

However, it should be recalled that a small number of species may reflect not only an influx of pollutants but also the character of the given ecosystem. In the clean high-mountain alpine brooks, the number of zoobenthic taxa ranges from several and from 10 to 20 (Kownacki 1991). Similarly, the species diversity of spring-fed streams or clean lowland rivers on sandy substrata are much lower than those even of highly-polluted foothill rivers on a stony substratum. This issue was discussed more fully in Kownacki (2000).

3.2.3. Higher taxonomic units

Higher taxonomic units are a very frequent basis for assessments of the environment. Examples here are families or orders, as well as their abundance and interrelationships. The characteristic groups in mountain rivers are Chironomidae, Simuliidae, Ephemeroptera, Plecoptera and Trichoptera, as well as Amphipoda in streams and brooks with high calcium content. Lowland rivers are in turn dominated by Oligochaeta, Chironomidae, Ephemeroptera, Trichoptera, and Mollusca. An influx of wastewaters changes the abundance and interrelationships of the different groups (Table VII).

In Western Europe, a high level of popularity is enjoyed by a different type of biotic index based on the abundance or percentage contribution of higher systematic groups. One of the first such was the Trent Biotic Index (TBI) devised for the River Trent in England (Woodiwiss 1964). As usual when an attempt is made to generalize on the basis of experience gained in a confined area, the index proved to be of limited suitability in assessing the quality of waters in other rivers. Work began on the creation of new indices of a more universal nature. Those in England include the BMWP (Biological Monitoring Working Party) index of Armitage *et al.* (1983), while the Belgians have developed the BBI (Belgian Biological Index) of De Pauw and Vanhooren (1983). A more detailed description of these indicators is to be found in Kudelska and Soszka (1996) and Soszka and Kudelska (2000).

The assessment of river water quality on the basis of higher taxonomic units would at present seem to be the most suitable for use in the practice of environmental monitoring. Its advantage lies in the simplicity and speed with which the zoobenthic material collected can be worked upon. The opportunity to present the obtained results in the form of simple indexes facilitates the encompassing of the method by legal standards. At the same time, a disadvantage lies in the loss of much of the valuable ecological information deriving from a species-based approach.

3.2.4. The taxocoen

The taxocoen is the assemblage of systematically-related organisms occurring in a defined environment with a dominance structure that repeats year after year (Chodorowski 1960*a*, 1960*b*). The assemblages of chironomids, mayflies, Turbellaria, or oligochaete worms are thus taxocoens. The assumptions underlying this approach resemble those in the case of the "species scale", where the basis is provided by species but differs in taking into account the abundance and dominance. The method was applied in the ecological assessment of Carpathian rivers using assemblages of Ephemeroptera (Sowa 1975), Trichoptera (Szczęsny 1986), and the Tatra brooks on the basis of chironomids (Kownacki 1971). Attempts at the classification and quality assessment of the waters in rivers and brooks have been made *inter alia* on the basis of taxocoens of mayflies (Kownacki 1980), Chironomidae (Srokosz 1980, Kownacki 1989), and oligochaetes (Dumnicka 1998). Sometimes it is worthwhile taking into account the frequency of occurrence as well as percentage shares. At two sites (2 and 3) along the Vistula, there is, for example, a lack of dominant species of chironomid on the basis of the "dominance index" (Table VIII).

An advantage of this system is the obtaining of a large amount of reliable ecological information. This means of river assessment is usually employed by specialists who are able to better interpretation the results. The disadvantage lies in the limitation of the ranges of most of the taxocoens to only a certain range of pollutant levels. Only the chironomid and oligochaete taxocoens show a wider spectrum where pollution is concerned. At present the sum total of information on this subject in Poland remains limited and requires the performance of further basic research before the system can here be recommended in practice. Nevertheless, it would seem likely that this system will come to dominate in the future assessment of water quality. Intensive research in this direction is currently being carried out both in the United States and Western Europe (Hart and Fuller 1974, Hubbard and Peters 1978, Beck 1977).

Table VII. The effect of pollutants on the fauna of selected rivers and streams in Poland.

Parameters	Rivers and streams, periods of studies, and investigated			
	Rybi Potok in Tatra Mts, 1971–1972[a]		Dunajec below Nowy Targ[b]	
	30 m below sewage outlet	3200 m below sewage outlet	1963–1964	1992–1993
	Stones	Stones	Stones	Stones
Mean and maximum values of physico-chemical factors				
pH	7.1	7.0		7.8
Oxygen saturation (%)	95.6	91.8		96.0
BOD_5 (mg L^{-1})	9.7	3.04		3.8
Oxidability (mg L^{-1})	2.16	1.92		11.3
Total phosphorus (mg P L^{-1})				
PO_4-P (mg PO_4 L^{-1})	0.26	0.10		
NH_4-N (mg N L^{-1})	0.356	0.106		
NO_2-N (mg N L^{-1})	0.005	0.003		
NO_3-N (mg N L^{-1})	0.445	0.480		
Chlorides (mg L^{-1})	1.05	1.1		15.0
Composition of macrofauna (%)				
Turbellaria	0.11	0.85		
Nematoda	4.68	0.02		
Gastropoda		0.009	1.45	0.15
Bivalvia	0.03			
Oligochaeta	4.47	0.78	0.47	60.05
Hirudinea			0.02	0.7
Isopoda				
Amphipoda				
Ostracoda	1.65	0.04		
Hydracarina	0.03	0.32	1.52	0.01
Ephemeroptera	0.85	26.4	9.08	2.93
Plecoptera	4.82	5.06	3.37	0.006
Odonata				
Heteroptera				
Coleoptera			0.04	0.003
Sialis sp.				
Trichoptera	0.19	1.96	39.23	0.75
Chironomidae	80.43	53.33	36.54	34.03
Other Diptera	2.1	11.1	8.25	1.97
Average density (ind. m^{-2})	197778	20702	4961	92999

[a] Bombówna 1977, Kownacki 1977;
[b] Dratnal and Szczęsny 1965, Szczęsny 1995;
[c] Starmach1948, Dumnicka and Kownacki 1988, Kasza 1988;
[d] Wielgosz 1979;
[e] Biesiadka and Kasprzak 1977

habitats									
Vistula above Cracow[c]				River Łyna[d]			River Warta, 1974–1975[e]		
1942–1943		1982–1983		Above Olsztyn	Within Olsztyn	Below Olsztyn	Above Poznan	Within Poznań	Below Poznan
Stones	Sand	Stones	Mud, sand				Sand, mud	Sand, mud	Mud, sand
7.4		7.2	7 2	7 1	7 0	7.0			
76.5				82.5	75 5	75 5			
		14 2	21.5	3 9	9 2	9 2			
6 2		15.6	15 7						
0 028		0.14	0.16	8 2	12.7	12.7			
				0 18	0 67	0.67			
				0.14	1.02	1 02			
				0 01	0.007	0.007			
				0 09	0.12	0.12			
45.9		849 4	820 0	9 3	12 3	12 3			
							+	+	
				0 2	0 1	0.1			
3 8		1 2		11.2		+	11 8	19 2	6 1
				2 3			1.7	1 2	0 2
57 3	90 8	63 6	99 9	32 9	95 5	92.9	20.3	19.0	73.6
4 6		0 6		1.7	+	0.1	7 0	19 0	9 8
1.5				0 6	+		0 92	0.8	0.2
				5 3			4.2	0 8	
							0 07	0 2	
9 5				1 9					
0 1									
0.1				+			12 4	5.0	2.1
				0.5	+		2.62	0 8	0 1
				0 6					
				1 3					
1.1				1.2			10 6	12 9	2 8
22 9	3.14	34.6	0 1	37.8	4 4	6.9	28.1	20 8	4.3
	5.6			1 7	+				
5233	612	47182	276136						

Table VIII. The dominance structure of the chironomid taxocoen in the Vistula between Oświęcim and Kraków, established on the basis of percentage shares and the dominance index (after Kownacki 1989).

Parameters	Stations					
	1	2	3	4	5	6
Chemical features						
Dissolved oxygen (mg L^{-1})	4.2	4.6	8.6	8.9	9.2	8.4
BOD_5 (mg L^{-1})	20.0	16.3	21.5	14.4	14.2	15.9
Oxidability (mg L^{-1})	19.0	16.0	15.7	15.0	15.6	15.9
NH_4-N (mg L^{-1})	5.5	3.6	3.7	3.5	3.6	3.1
Phosphate (mg PO_4 L^{-1})	0.16	0.17	0.16	0.16	0.14	0.14
Total phosphorus (mg P L^{-1})	1.1	1.3	9.1	2.5	1.3	1.3
Chlorides (mg L^{-1})	874	824	820	807	849	860
Dominance (%)						
Cricotopus (C.) bicinctus (Meigen)	49	11	33	30	54	21
Chironomus sp. ("*thummi*")	19	10			+	+
Parachironomus arcuatus (Goet.)		43	11	5.9	2.0	4.7
Chironomini (juv.)	4.8	21	11	3.9	+	1.9
Thienemannimyia group	9.7	10	11	2.6	+	+
Bryophenocladius sp.			11			
Orthocladiinae (juv.)	9.7		11	6.3	6.4	7.3
Dicrotendipes nervosus (Staeger)	4.8			50	37	63
Chironomidae density (ind. m^{-2})	391	229	206	1014	16330	6745
Dominance index						
Cricotopus (C.) bicinctus (Meigen)	11	1.0	2.9	16	46	19
Dicrotendipes nervosus (Staeger)	+			37	36	63
Chironomus sp. ("*thummi*")	1.3	1.3			+	+
Parachironomus arcuatus (Goet.)		4.3	1.0	2.9	1.5	3.7
Chironomini (juv.)	+	4.3	1.0	1.7	+	+
Thienemannimyia group	+	1.0	1.0	+	+	+
Orthocladiinae (juv.)	+		1.0	1.5	4.2	2.9
Bryophenocladius sp.			1.0			

3.2.5. The dominance structure of macroinvertebrate assemblages

Not all the species in an assemblage are of equal importance, and it is usual for just a few to occur very abundantly, while 10–20 are abundant and the remaining tens or hundreds of species are encountered as single specimens only. The determinant of dominance may be the abundance in terms that are absolute (ind. m^{-2}) or relative (the percentage share of a given taxon in relation to the abundance of the whole fauna). In describing dominance on the basis of percentage shares, dominants may be taken to be those species exceeding 10%, sub-dominants those in the range 1–9.9%, and adominants those below 1% (Kownacki 1971). Dominance may also be described on the basis of a "dominance index" given by the formula:

$$d = F\,n/(100\,N)$$

where n is the abundance of the given species, N the overall abundance of the fauna, F the frequency of occurrence of the given species, for example calculated as the ratio f_i/f, where f_i is the number of samples in which the ith species occurs and f the overall number of samples collected (Kownacki 1971).

Dominant species are those which are ecologically highly successful (Krebs 1972). A clean river usually has 3–4 taxa that dominate with a similar percentage share or "dominance index". As pollution increases, the number of dominant taxa either declines or else remains constant but with one species attaining a very high value for abundance at the expense of all the others. The way of making such an assessment of pollution can be presented using the example of the macroinvertebrate communities on the Dunajec below the point of wastewater discharge in Nowy Targ (Fig. 3).

The dominance structure of a macroinvertebrate community has been applied in descriptions of natural faunal communities in running waters (Kownacki 1991), as well as in the assessment of pollutants (Ghetti and Bonazzi 1977, Dratnal 1976, Kownacki 1977, 1983, Kownacki *et al.* 2000). The method requires a precise designation and counting of the different taxa, which implies a good knowledge of the systematics of basic groups of fauna. At present the use of this method is possible with a large scientific team comprising many specialists – as was the case of the description of the macroinvertebrate communities of the Dunajec (Szczęsny 1995). The interpretation of the material is also difficult, requiring considerable experience. At the present time there is too little information on the "dominance structure of a community" for this method to be recommended in the routine monitoring of rivers. However, such studies should be carried out by scientific team as results obtained may in future become the basis for the reliable assessment of changes in the river environment.

4. Assessment of water quality

In assessing water quality in rivers on the basis of benthic macroinvertebrate communities, several classes of river purity may be identified:

1. Clean waters – with a high species diversity or richness (numerous representatives of the Ephemeroptera, Trichoptera, and Plecoptera in mountain rivers), well-marked dominance structure, varying abundance, and low biomass.

2. Slight pollution – increased abundance of fauna, no change in dominance structure.

3. Moderate pollution – species composition unchanged, but their rank changes among the community, change in the ratios between the systematic groups (increasing abundance of Oligochaeta and a declining share of Chironomidae, Ephemeroptera and Trichoptera), with abundance and biomass high.

4. Strong pollution – dominance structure changes, species untypical of the given ecological zone predominate, with these usually being characteristic of lower sections of rivers or typical of alluvial shoreline habitats.

5. Very strong pollution – mass occurrence of Oligochaeta, representatives of other groups (Chironomidae, Hirudinea, and Mollusca) present sporadically or not at all (Ephemeroptera, Plecoptera and Trichoptera).

6. Poisoned water – fauna absent, or present only as single specimens of fly larvae breathing atmospheric air (*Eristalis, Psychoda*).

It should be emphasised that these conclusions are preliminary in character. Further research should provide a more precise linkage between the fauna community and a river water quality class. Furthermore, there is no chance of creating a universal system for the biomonitoring of rivers in the whole country. It is necessary to regard always the ecological factors, such as the zonal distribution of fauna communities along river course, habitats and the season of the year. As well as, there is impossible to adopt automatically into Polish conditions the methods elaborated in other countries for other types of rivers.

References

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 macroinvertebrate over a wide range of unpolluted running-water sites. Wat. Res., 17, 333–347.

Beck W M. Jr 1977. Environmental requirements and pollution tolerance of common freshwater Chironomidae. Cincinnati, US Environmental Protection Agency (Environmental Monitoring Series, EPA-600/4-77-024), 260 pp.

Biesiadka E and Kasprzak K 1977. An investigation on the macrofauna of the River Warta within the city Poznań Acta Hydrobiol., 19, 109–122.

Bombówna M. 1977. Biocenosis of a high mountain stream under the influence of tourism 1. Chemism of the Rybi Potok waters and the chlorophyll content in attached algae and seston in relation to the pollution Acta Hydrobiol., 19, 243–255.

Botosaneanu L 1988. Zonation et classification biologiques des cours d'eau Développement récents, alternatives, perspectives. Proc. 15th Congr. Naz Ital Ent., L'Aquila, 33–61.

Brittain J.E. and Eikeland T.J 1988 Invertebrate drift, a review. Hydrobiologia, 166, 77–92.

Chodorowski A 1960*a*. Les taxocénes des Turbellariés et la méthode de leur étude Ekol Pol., B, 6, 95–114 [in Polish with French summary]

Chodorowski A 1960*b*. Taxocenes comme l'unité de la biocénologie descriptive. Ekol Pol., B, 6, 301–304 [in Polish with French summary].

De Pauw N. and Vanhooren G 1983 Method for biological quality assessment of watercourses in Belgium. Hydrobiologia, 100, 153–168

Dratnal E. 1976. Benthic invertebrate communities of the Prądnik stream. Ochr. Przyr., 41, 281–321 [in Polish with English summary].

Dratnal E., Sowa R. and Szczęsny B. 1979. Benthic invertebrate communities in the Dunajec river between Harklowa and Sromowce Niżne. Ochr. Przyr., 42, 183–215 [in Polish with English summary].

Dratnal E and Szczęsny B (eds) 1965 Benthic fauna of the Dunajec river Kom Zagosp. Ziem Górskich PAN, 11, 161–214.

Dumnicka E 1998 Ustalanie indeksów biotycznych na podstawie organizmów makrobentosu [Establishing of biotic indexes on the basis of macrobenthic organisms]. In: Suchy M (ed.) Mikrobiologiczne metody w monitoringu środowiska przyrodniczego [Microbiological methods in environmental monitoring] Rzeszów, PIOŚ (Biblioteka Monitoringu Środowiska), 53–64 [in Polish].

Dumnicka E and Kownacki A 1988 A regulated river ecosystem in a polluted section of the Upper Vistula. 8 Macroinvertebrates Acta Hydrobiol., 30, 81–87.

Fjellheim A. and Raddun G. 1990. Acid precipitation: Biological monitoring of streams and lakes. The Science of the Total Environment, 96, 57–66.

Ghetti P. F and Bonazzi G. 1977 A comparison between various criteria for the interpretation of biological data in the quality of running waters. Water Research, 11, 819–831

Głowaciński Z. 1994 Species diversity – interpretation of the idea and methods of estimation. Roczniki Bieszczadzkie, 3, 25–41 [in Polish with English summary].

Gliwicz J. 1992. Biological diversity, a new concept of nature conservation Wiad Ekol., 38, 211–237 [in Polish with English summary].

Hart C.W. Jr and Fuller S.L.H. (eds) 1974 Pollution ecology of freshwater invertebrates. New York–London, Academic Press, 389 pp.

Hawksworth L. (ed) 1996. Biodiversity (measurement and estimation) London, Chapman and Hall, 122 pp

Hilbricht-Ilkowska A. 1998 Różnorodność biologiczna siedlisk słodkowodnych – problemy, potrzeby, działania [Biodiversity in freshwater habitats – problems, needs and activities] Idee ekologiczne, 13, Ser. Szkice 7, 13–54 [in Polish with English summary].

Hubbard M.D and Peters W.L 1978 Environmental requirements and pollution tolerance of Ephemeroptera Cincinnati, US Environmental Protection Agency (Environmental Monitoring Series, EPA-600/4-78-061), 461 pp

Hynes H B.N 1972. The ecology of running waters. Liverpool, Univ. Press, 555 pp.
Illies J. and Botosaneanu L 1963 Problemes et méthodes de la classification et de la zonation écologique des eaux courantes, considerées surtout du point de vue faunistique Mitt. Internat Verein Limnol., 12, 1–57.
Kasza H. 1988 A regulated river ecosystem in a polluted section of the Upper Vistula 2 Hydrochemistry. Acta Hydrobiol., 30, 15–22.
Kolkwitz R. 1950 Oekologie der Saprobien Schr. reihe Ver. Wasser-, Boden- und Lufthygiene 4, 1-64.
Kolkwitz R. and Marsson M 1909. Ökologie der tierischen Saprobien. Beiträge zur Lehre von biologischen Gewässerbeurteilung. Int. Rev. Ges. Hydrobiol, Hydrogr., 2, 126–152.
Kownacka M. and Kownacki A. 1972. Vertical distribution of zoocenoses in the streams of Tatra, Caucasus and Balkans. Verh Internat. Verein. Limnol., 18, 742–750.
Kownacki A 1971. Taxocens of Chironomidae in streams of the Polish High Tatra Mts. Acta Hydrobiol., 13, 439–464.
Kownacki A. 1977. Biocenosis of a high mountain stream under the influence of tourism. 4 The bottom fauna of the stream Rybi Potok (the High Tatra Mts). Acta Hydrobiol., 19, 293–312.
Kownacki A 1980 Taxocenes of Ephemeroptera in unpolluted and polluted streams of the Tatra Mountains. In: Flannagan J.F. and Marshall K.E. (eds) Advances in Ephemeroptera biology. New York–London, Plenum Press, 405–419.
Kownacki A. 1983. Stream ecosystems in mountain grassland (West Carpathians) 8. Benthic invertebrates. Acta Hydrobiol., 24, 375–390.
Kownacki A 1989. Taxocens of Chironomidae as an indicator for assessing the pollution of rivers and streams. Acta Biol Debr. Oecol. Hung., Suppl., 3, 219–230.
Kownacki A. 1991 Zonal distribution and classification of invertebrate communities in high mountain streams in South Tirol (Italy) Verh. Internat. Verein Limnol., 24, 2010–2014
Kownacki A. 2000. Diversity of benthic macroinvertebrates as a monitoring method for polluted rivers Acta Hydrobiol., 42, 207–214
Kownacki A., Margreiter M., Kawecka B and Kwandrans J 2000. Effect of treated wastes on cyanobacteria, algae, and macroinvertebrate communities in an alpine stream. Acta Hydrobiol., 42, 215–230.
Kownacki A and Starmach J. 1989 Ocena jakości wód Górnego Dunajca i kierunki zmian pod wpływem zabudowy hydrotechnicznej [Evaluation of water quality of the River Dunajec and its changes caused by hydrotechnical constructions]. Proc. Symp. "Dunajec wczoraj-dziś--jutro" [The past, present and future of the River Dunajec], Niedzica, 15 June 1989. Warszawa, SGGW-AR (Publ CPBP 04 10, 11), 96–108 [in Polish].
Krebs C. J. 1972 Ecology The experimental analysis of distribution and abundance. New York–Evanston–San Francisco–London, Harper and Row Publ., 694 pp
Kudelska D. and Soszka H 1996. Przegląd stosowanych w różnych krajach sposobów oceny i klasyfikacji wód powierzchniowych [An overview of the methods used in several countries of assessment and classification of surface waters]. Warszawa, Biblioteka Monitoringu Środowiska, 83 pp. [in Polish].
Liebemann H. 1951. Handbuch der Frischwasser- und Abwasserbiologie (vol. 1). München, 539 pp
Margreiter-Kownacka M., Pechlaner R., Ritter H. and Saxl R. 1984. Die Bodenfauna als Indicator für den Saprobitätsgrad von Fliessgewassern in Tirol. Ber nat.-med. Verein Innsbruck, 71, 119–135.
Moller Pillot H.K.M. 1971. The assessment of pollution in lowland streams by means of macrofauna. Tilburg, Pillot-Standaardboekhandel, 286 pp [in Dutch with English summary].
Mouthon J. 1996 Molluscs and biodegradable pollution in river, proposal for a scale of sensitivity of species Hydrobiologia, 317, 221–229.
Mouthon J. and Charvet S. 1999. Compared sensitivity of species, genera and families of Molluscs to biodegradable pollution. Annls Limnol., 35, 31–39.
Ordinance 1991. Rozporządzenie Ministra Ochrony Środowiska, Zasobów Naturalnych i Leśnictwa z dnia 5.11 1991 w sprawie klasyfikacji wód oraz warunków, jakim powinny opowiadać ścieki wprowadzane do wód lub ziemi [Ordinance of the Minister of Environment Protection, Natural Resources and Forest Management of November 5, 1991, concerning

water quality classification and required condition of sewage discharged into waters and soils]. Dz. Ust. RP Nr 116, Poz. 503, 1579–1583 [in Polish].
Piechocki A. 1979. Mięczaki (Mollusca), ślimaki (Gastropoda) [Molluscs (Mollusca), snails (Gastropoda)]. Warszawa, PWN (Fauna Słodkowodna Polski, 7), 187 pp. [in Polish].
Piechocki A. and Dyduch-Falniowska A. 1993. Mięczaki (Mollusca), małże (Bivalvia) [Molluscs (Mollusca), bivalves (Bivalvia)]. Warszawa, PWN (Fauna Słodkowodna Polski, 7A), 200 pp. [in Polish].
Rosenberg D.M. and Resh V.H. (eds) 1992. Freshwater biomonitoring and benthic macroinvertebrates. New York-London, Chapman and Hall, 488 pp.
Sadovskij A.A. 1940. Problema saprobnosti v gornyh rekah [Saprobity problems in mountain rivers]. Soobs. Gruz. Fil. AN SSSR, 1, 369–376 [in Russian].
Saether A.O. 1975. Nearctic chironomids as indicators of lake typology. Verh. Internat. Verein Limnol., 19, 3127–3133.
Saether O.A. 1979. Chironomid communities as water quality indicators. Holarctic Ecology, 2, 65–74.
Sládeček V. 1973. System of water quality from the biological point of view. Arch. Hydrobiol. Beih. Ergebn. Limnol., 7, 1–218.
Sowa R. 1975. Ecology and biogeography of mayflies (Ephemeroptera) od running waters in the Polish part of Carpathians. 1. Distribution and quantitative analysis. Acta Hydrobiol., 17, 223–297.
Soszka A. and Kudelska D. 2000. Macroinvertebrate-based biological methods of assessing river quality applied widely in European countries. Acta Hydrobiol., 42, 263–272.
Srokosz K. 1980. Chironomidae communities of the River Nida and its tributaries. Acta Hydrobiol., 22, 195–215.
Starmach K. 1948. The age and growth of barbel (*Barbus barbus* L.) fished in the River Vistula near Cracow. Prace roln.-leśne PAU, 39, 1–42 [in Polish with English summary].
Starmach K., Wróbel S. and Pasternak K. 1976. Hydrobiologia – limnologia [Hydrobiology – limnology]. Warszawa, PWN, 621 pp. [in Polish].
Steffan A.W. 1971. Chironomid (Diptera) biocenoses in Scandinavian glacier brooks. Can. Entomol., 103, 477–486.
Szczęsny B. 1986. Caddisflies (Trichoptera) of running waters in the Polish North Carpathians. Acta Zool. Cracov., 29, 501–586.
Szczęsny B. (ed.) 1995. Degradation of the benthic invertebrate fauna of the Dunajec river in the neighbourhood of Pieniny National Park (Southern Poland). Ochr. Przyr., 52, 207–224 [in Polish with English summary].
Thienemann A. 1954. Leben, Verbreitung und wirtschaftliche Bedeutung der *Chironomus*. Die Binnengewasser, 20, 834 pp.
Turoboyski L. 1979. Hydrobiologia techniczna [Sanitary hydrobiology]. Warszawa, PWN, 444 pp. [in Polish].
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.
Ward J.V. 1992. Aquatic insect ecology. 1. Biology and habitat. New York-Chichester–Brisbane–Toronto–Singapore, J. Wiley and Sons, 438 pp.
Waters T.F. 1962. Diurnal periodicity in the drift of stream invertebrates. Ecology, 43, 316–320.
Wiederholm T. 1980. Use of benthos in lake monitoring. J. Wat. Pollut. Cont., 52, 537–547.
Whitton B.A.(ed.) 1984. Ecology of European rivers. Oxford-London–Edinburgh–Boston–Palo Alto–Melbourne, Blackwell Sci. Publ., 644 pp.
Wielgosz S. 1979. The effect of wastes from the town of Olsztyn on invertebrate communities in the bottom of the River Łyna. Acta Hydrobiol., 21, 149–165.
Woodwiss F. S. 1964. The biological system of stream classification used by the Trent River Board. Chemistry and Industry, 83, 443–447.
Wróbel S. (ed.) 1998. Environmental degradation of the Czarna Wisełka and Biała Wisełka catchments, Western Carpathians. Studia Nature, 44, 223 pp.
Zelinka M. and Marwan P. 1961. Zur Präzisieruung der Reinheit fließender Gewässer. Arch. Hydrobiol., 57, 389–407.