

**Longitudinal patterns in fish communities  
in a Polish mountain river:  
their relations to abiotic and biotic factors**

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**Abstract** — In the River Stradomka the number of fish species and their diversity are highly correlated with the physical parameters of the catchment. The density and biomass of fish are significantly associated with chlorophyll *a* in the periphyton. High concentrations of calcium did not affect the fish community. The number and biomass of the brown trout decreased in relation to the stream order. The author's hypothesis is that the abiotic factors dominate the regulation of upstream fish communities while fishes further downstream seem to be dominated by biotic factors.

**Key words:** mountain river, fish communities, river continuum concept, abiotic/biotic factors.

## **1. Introduction**

In classic studies on the structure of fish populations along the course of rivers, communities in different countries were classified according to static zonal models (Huet 1959, Illies, Botosoneanu 1963, Whiteside, McNatt 1972, Horowitz 1978). In southern Poland these types of investigation were carried out by Starmach (1956), Kolder et al. (1974), and Starmach (1983/1984).

In recent years, opinions concerning stream ecology evolved under the influence of the river continuum concept (RCC) (Vannote et al. 1980), a holistic theory explaining the structure and dynamics of metabolic processes in running waters. The concept assumes that the coalescing network of streams in a river drainage basin is a continuum

of physical gradients with associated biotic adjustments. Zalewski and Naiman (1985) applied this approach to the dynamics of fish communities in the regulatory abiotic-biotic continuum concept (RABC).

In analysing the relationship of the stream order to processes occurring in fish communities, it is necessary to test four conditions given by Platts (1979), namely: (1) stream order must relate to geomorphic features of the drainage system studied, (2) the drainage system should be in a natural state, (3) the fish communities should be unexploited, and (4) the drainage should be geologically mature and subject to well-defined geomorphic processes. The River Stradomka satisfies all of these conditions.

The aim of the present study was to examine the qualitative and quantitative relations between the changes in parameters describing the fish community (structure, density, diversity, biomass, and production) with the longitudinal, abiotic variation of habitats and water quality, and the variation of biotic environmental factors, such as standing stock of carbon in bottom communities.

## 2. Study area

The River Stradomka flows through the territory of the Carpathian foothills (Western Carpathians) and drains an area of 368 km<sup>2</sup> between the Beskid Wyspowy Mountain range (from the south) and Wiśnicz foothills (from the north). The Stradomka is the largest right hand tributary of the River Raba (the Upper Vistula Basin). It flows out of a number of sources at an altitude of about 690 m from under Mount Śnieżnica (1007 m) and Mount Wierzbanowska Góra (778 m). The river is 40 km in length and has three subcatchments: the Tarnawa (97 km<sup>2</sup>), Trzciański Potok (60.5 km<sup>2</sup>), and Polanka (63.1 km<sup>2</sup>). For the most part the Stradomka shows the typical montane characteristics of variable flow and sinuous channel. The river is shallow with a stony and gravelly bed (Punzet 1969) and includes five stream orders (Strahler 1957) (fig. 1).

The mean annual air temperature is 5.0–7.5°C, and the mean annual precipitation 750–900 mm. The geological structure of the basin is very varied, being composed chiefly of flysch formations and chalk (Pasternak 1969). In the part of the Stradomka studied there were no aquatic macrophytes.

## 3. Material and methods

In the first and second order streams fish were absent owing to such unfavourable hydrological conditions as high current velocity  $>1 \text{ m s}^{-1}$ ,

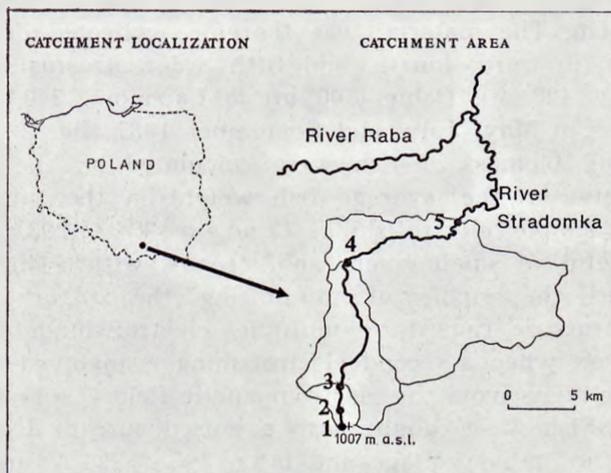


Fig. 1. Localization of the study area and position of investigated sites (numbers denote also the order of stream) in terms of the partial subcatchments of the River Stradomka

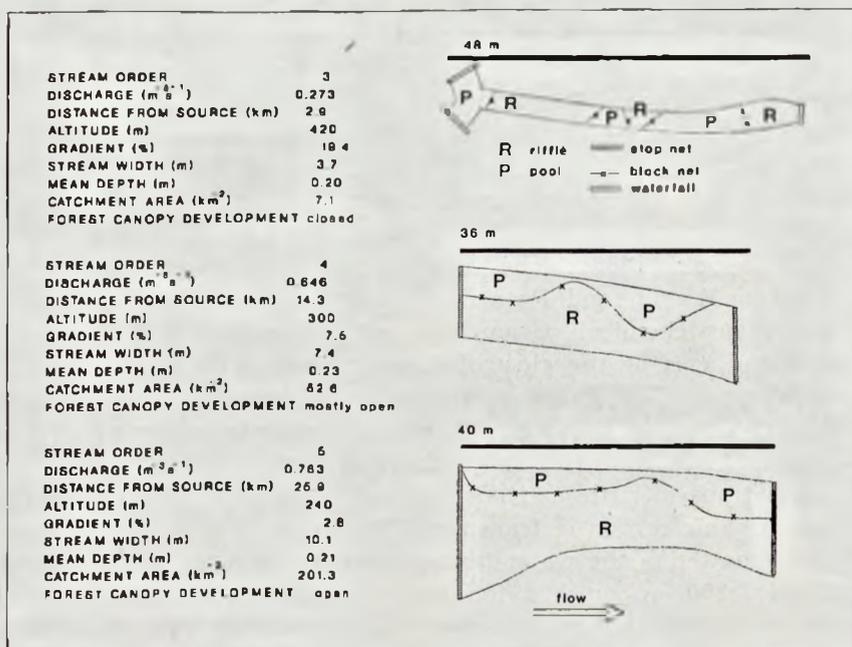


Fig. 2. Physical parameters for 3 stations in different stream orders used in this study (discharge — annual mean; width and depth — averages for the entire stream section measured at base flow; gradient — average for the entire stream section)

gradient  $>25\%$ , river waterfalls  $>2$  m, and a low water level in the summer  $<5$  cm. The material was therefore collected downstream at three stations (in third, fourth, and fifth order streams) (fig. 1) from Skrzydlina (alt. 420 m), Dąbie (300 m) to Łapanów (240 m), on three sampling dates in May, July, and September 1987 (fig. 2).

Density and biomass of fish were calculated on the basis of relationships between the average fish weight in the sample and the efficiency of simple electrofishing (Zalewski, 1993, 1985). This method is useful in small rivers and streams with a highly variable habitat. It has the virtue of minimizing the disturbance of fish community structure caused by multiple electrofishing (Zalewski, 1986). Moreover, when a second electrofishing is involved many mobile fish species actively avoid the electromagnetic field (Zalewski, Penczak, 1981). Fish were caught with a pulsed current UIP-12 electroshocker with an initial voltage and intensity of 220 V and 3.5 A and a frequency regulation in the range from 20–100 Hz. At each station and on each occasion, fish were collected from down- to upstream in enclosed areas. The stream was isolated by waterfalls or by stop nets. Within the stream two distinct habitats (riffle and pool) were separated by blocking nets (fig. 2). In the fourth and fifth stream order, owing to the river width ( $>7$  m), two parallel-moving teams were used. After each sampling the fish were recorded, measured (to the nearest mm), and weighed (to the nearest g) in the field, and released. To avoid the negative effect of low temperature on the electrofishing (Lamarque, 1967) samples were taken only at temperatures above  $10^{\circ}\text{C}$ . The conductivity did not effect electrofishing efficiency ( $>185 \mu\text{S cm}^{-1}$ ). The diversity of the fish assemblage in terms of density and biomass was calculated according to the Shannon-Weaver formula (Shannon, Weaver 1963). The annual fish production was estimated according to Mann and Penczak (1984).

The physico-chemical parameters and biological material were collected in the area of the electrofishing at each sampling occasion. The concentration of DOC (dissolved organic carbon) in the water was determined using a Backmann Carbon Analyser. Retention organic carbon ratio (ROCR) of sedimented seston was estimated using 1-litre cylindrical traps in riffle and pool habitats over 24 h. Macroinvertebrate drift and organic carbon in transport (TOC) were determined by catching suspended matter in the water (except for every fine particular carbon — VPOC) in  $>300 \mu\text{m}$  mesh nylon nets in a diel cycle at 3 h intervals. The drift was counted and weighed; the content of organic carbon was determined from the ash free dry weight (AFDW) (Wetzel 1975). Net daily metabolism (NDM) of bottom communities was estimated from the difference in oxygen consumption over a 24 h period when stones were transferred to light and dark cylinders without disturbing their

associated biota. Periphyton was collected from rock areas delimited with a ring (Douglas 1958), and the determinations included AFDW (drying at 60°C for 24 h and combustion at 600°C) and chlorophyll *a* concentration (Golterman, Clymo 1969). The mean ratio of organic carbon contained in chlorophyll *a* to organic carbon in AFDW ( $C_{chl.a}/C_{AFDW} = 4.5 \cdot 10^3$  for  $n = 9$ ) was found for the periphyton. In five Surber samples of bottom fauna each from 400 cm<sup>2</sup> of riffle and pool habitats, the taxonomic composition, density, biomass (AFDW), and the structure of functional feeding groups (Cummins 1974) were determined.

## 4. Results

### 4.1. Environmental components

All physico-chemical factors (except pH) increased with stream order (with maxima in the fifth stream order) (fig. 3). The greatest coefficient of variance ( $C_v$ ) of five abiotic variables — temperature (21%), pH (13%), O<sub>2</sub> (11%), N-NH<sub>4</sub> (70%), and P-PO<sub>4</sub> (60%) — ecologically important for the fish, was found in the middle, fourth order stream.

No significant differences of DOC were observed between stations. A high index of ROCR was found in a fifth order stream (121.9 g m<sup>-2</sup> day<sup>-1</sup>) while in the seston of a third order stream there was the greatest amount of TOC (14.2 mg dm<sup>-3</sup>) and the highest diel density of invertebrate drift (45 indiv. m<sup>-2</sup>,  $C_v = 61\%$ ). No significant changes were noted in the structure of the periphyton. Between the third and fifth orders *Cladophora glomerata* predominated (90%) with regard to biomass and Bacilliarophyceae with regard to numbers. The content of chlorophyll *a* in the periphyton varied from 51–566 mg m<sup>-2</sup>. The greatest average value of carbon in the periphyton biomass (25.8 g C m<sup>-2</sup>) was found in the fourth order stream. The composition of the macroinvertebrate community changed distinctly with increasing stream order. With regard to biomass first Ephemeroptera (third order stream) and later Diptera (fourth and fifth order) prevailed. The greatest average biomass of bottom fauna (4.02 g m<sup>-2</sup>) was found in the third order stream and the poorest association occurred in the fourth order one (diversity index  $H = 0.87$ ). With increasing stream order the share of shredders decreased and that of collectors increased (fig. 3). In the third order stream the macrofauna varied most in density ( $C_v$  86%), biomass (185%), and share of functional feeding groups (shredders — 91%, collectors — 42%).

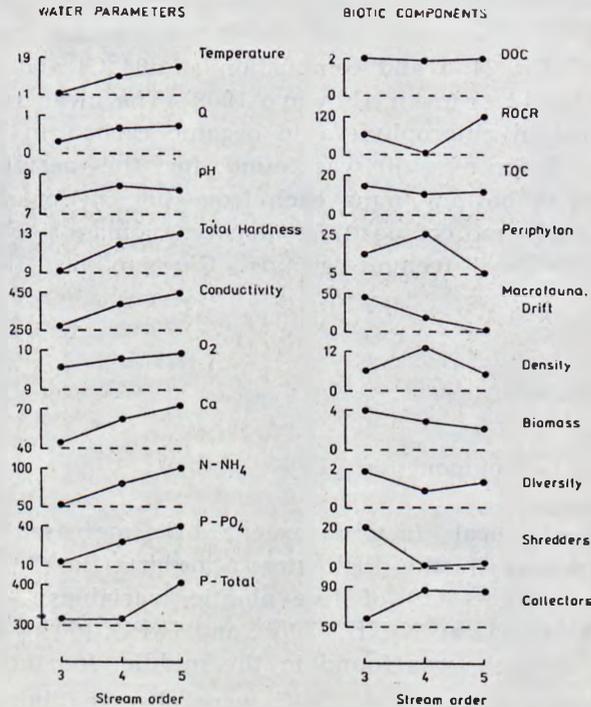


Fig. 3. Physico-chemical averages of water parameters and biotic components in relation to stream order. Units: temperature — °C, Q (mean annual discharge) —  $\text{m}^3 \text{s}^{-1}$ , total hardness — °d, conductivity —  $\mu\text{S cm}^{-1}$  (20°C),  $\text{O}_2$  —  $\text{mg dm}^{-3}$ , Ca —  $\text{mg dm}^{-3}$ ,  $\text{N-NH}_4$  —  $\mu\text{g dm}^{-3}$ ,  $\text{P-PO}_4$  —  $\mu\text{g dm}^{-3}$ , P-total —  $\mu\text{g dm}^{-3}$ , DOC —  $\text{mg dm}^{-3}$ , ROCR —  $\text{g m}^{-2} \text{day}^{-1}$ , TOC —  $\text{mg dm}^{-3}$ , periphyton —  $\text{g C m}^{-2}$ , drift —  $\text{indiv. m}^{-2}$ ; macrofauna: density —  $10^8 \text{m}^{-2}$ , biomass —  $\text{mg C m}^{-2}$ , shredders and collectors — % of density

#### 4.2. Longitudinal patterns of the fish community

Altogether, 10 fish species from 4 families were recorded: Salmonidae (*Salmo trutta m. fario* L.), Cottidae (*Cottus poecilopus* Heckel), Cyprinidae (*Barbus barbus* (L.)), *Barbus petenyi* Heckel, *Gobio gobio* (L.), *Phoxinus phoxinus* (L.), *Alburnoides bipunctatus* Bloch, *Chondrostoma nasus* (L.), *Leuciscus cephalus* (L.), and Cobitidae (*Noemacheilus barbatulus* (L.)). In the third order sector the fish community was poor and composed of two rheophile species: brown trout and bullhead. These species showed a limited range of distribution and when the parameters of habitat changed the fish were replaced by representatives of the families Cyprinidae and Cobitidae (fig. 4). The number of species increased linearly with increasing stream order ( $P < 0.05$ ;  $r^2 = 0.78$ ). The number of species in riffle and pool was signifi-

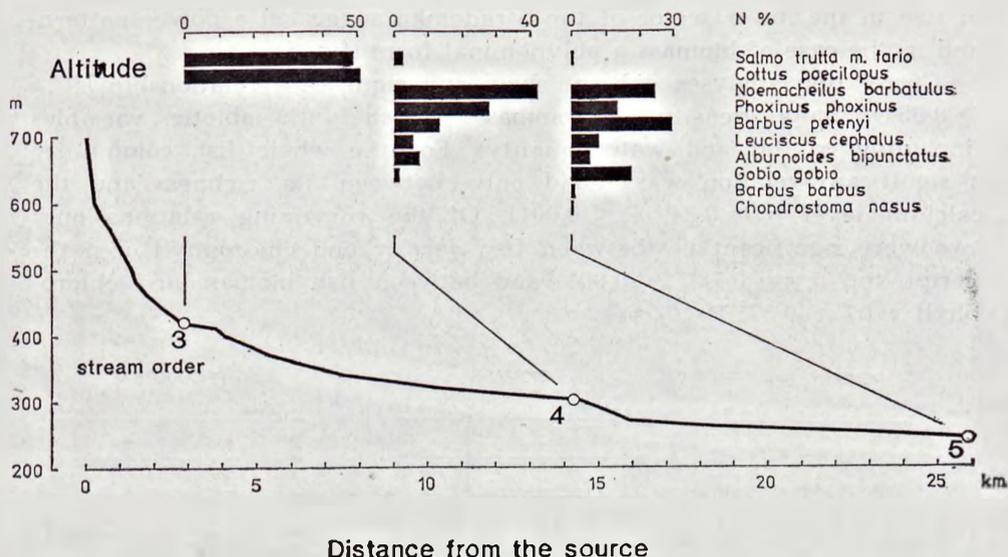


Fig. 4. Longitudinal distribution and percentage composition of fish communities in three stream orders of the River Stradomka

cantly correlated ( $P < 0.001$ ) with gradient ( $r = -0.88$ ), stream order ( $+0.89$ ), and distance from the sources ( $+0.89$ ). Highly significant correlations were also found between the number of species and the physico-chemical parameters of the water (Table I).

The mean seasonal density of fish in the Stradomka reached  $1.89 \text{ indiv. m}^{-2}$  (with a range of 0.2–16 between habitats), the average biomass being  $19.2 \text{ g m}^{-2}$  (11.6–38.2). The highest mean annual density occurred in the fifth ( $2.7 \text{ indiv. m}^{-2}$ ) and the maximum biomass in the fourth order streams ( $25.1 \text{ g m}^{-2}$ ). The relations of fish density and biomass to stream order were regressed using several models, and the two most significant relations were selected. The maximum mean density

Table I. Correlation of number of fish species (N) with physico-chemical parameters in the River Stradomka (levels of significance: \*\*\* —  $P < 0.001$ ; \*\* —  $P < 0.002$ ; \* —  $P < 0.001$ ; NS — non-significant)

	Temperature	pH	Total hardness	Conductivity
N	0.74 ***	0.66 **	0.89 ***	0.86 ***
	O <sub>2</sub>	Ca	N-NH <sub>4</sub>	P-PO <sub>4</sub>
N	NS	0.84 ***	NS	0.55 *

of fish in the lower sector of the Stradomka suggested a power pattern, and in the case of biomass a polynomial form (fig. 5).

Correlation analyses did not show any significant relationship ( $P > 0.05$ ) of total density and biomass of fish with abiotic variables (including habitat and water quality). For the whole fish community a significant relation was found only between its richness and the calcium level ( $r = 0.84$ ,  $P < 0.001$ ). Of the remaining relations only two were significant i.e. between fish density and chlorophyll *a* in the periphyton ( $r = 0.78$ ,  $P < 0.001$ ) and between fish biomass and chlorophyll *a* ( $r = 0.57$ ,  $P < 0.05$ ).

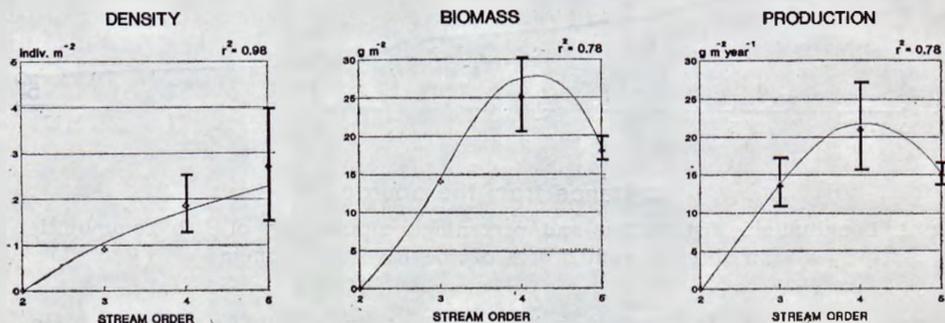


Fig. 5. Longitudinal patterns of fish communities in the River Stradomka. The power regression line for the density model is of the form  $y = 1.09 (x-2)^{0.61}$ ; for fish biomass and production the polynomial models are of the following forms:  $y = 27.17 - 46.03x + 21.25x^2 - 2.47x^3$  and  $y = 24.0 - 40.4x + 18.5x^2 - 2.16x^3$ , respectively

The community diversity calculated with regard to density ( $H_D$ ) and biomass ( $H_B$ ) of fish showed a linear dependence (in both cases) in relation to stream order. The fish diversity (in terms of density and biomass) was also significantly related to river gradient (respectively:  $-0.82$ ,  $-0.99$ ) and to distance from the sources ( $0.86$ ,  $0.89$ ).

The highest total fish production in relation to the stream order was found in the fourth order stream ( $20.93 \text{ g m}^{-2} \text{ year}^{-1}$ ) (fig. 5). In the third order stream the fish production was half that value. The stream order accounted for 78.2% of the variation in fish production. The production maximum in the fourth order stream suggests the occurrence of a polynomial dependence of fish production on stream order.

## 5. Discussion

The Abiotic/Biotic Regulatory Continuum concept (Zalewski, Naiman 1985) assumes that in different types of stream there occurs a shift in the mode of regulation from abiotic to biotic along the stream

order, temperature regime and gradient. The abiotic variation in fish habitats and intensity of dynamics of biological processes account for energy flow to the highest trophic level (Elliott 1987). The number of fish species and diversity of the community increases linearly with stream order with a maximum in the fifth order (this study, Whiteside, McNatt 1972).

In the Stradomka, the density, biomass, and fish production do not correlate with the stream order according to a linear model. The distribution of density runs according to a power model and the longitudinal distribution of biomass and production are of polynomial form. This production relationship corresponds to a similar mathematical model suggested by Morin and Naiman (1990). It seems that the occurrence of the maxima in the middle sector represents the response of fish assemblages to a pronounced environmental variation (temperature, pH, O<sub>2</sub>) (Vannote et al. 1980), an increased level of nutrients (N-NH<sub>4</sub> and P-PO<sub>4</sub>) (Newbold et al. 1981), and the highest density of periphyton and macrofauna. The present study did not confirm significant correlations between the calcium content and total fish biomass claimed by Włodek (1976) and Zalewski et al. (1990).

In the Stradomka there occurs a shift in the structure of carbon standing stock from allochthonous matter (CPOC) and macrofauna biomass (shredders) in the third order to the biomass of periphyton and detritus (FPOC) which are processed in middle and lower sectors by collectors (Minshall et al. 1983) and fish communities. Naiman and Sedell (1979) concluded that most carbon is stored in lower stream orders and consumed by communities below. With higher stream order the retention potential of habitats increases, corresponding with a decrease in TOC and in the level of macrofauna drift. Hence the intensity of organic matter utilization (maximum spiraling, Newbold et al. 1981) by the communities of consumers in the fourth and fifth orders increases distinctly. The effect of these processes is a shift in metabolism of the system from heterotrophy to autotrophy, which is intensified by a parallel shift in forest canopy development (fig. 6).

Apart from the complex response of fish communities, a simple response of separate species was observed in the Stradomka. The brown trout was affected by abiotic factors which limited its number and biomass downstream (fig. 7). Its density and biomass were correlated ( $P < 0.01$ ) with the gradient, stream order, and distance from the sources, and with the physico-chemical parameters of the water (Table II). Lanka et al. (1987) showed that the biomass of four salmonids chiefly depended on geomorphic variables of the environment while biological factors did not significantly affect the number and biomass of trout. This supports the hypothesis that upland fish communities are dominated by abiotic factors (Zalewski et al. 1990). In general it

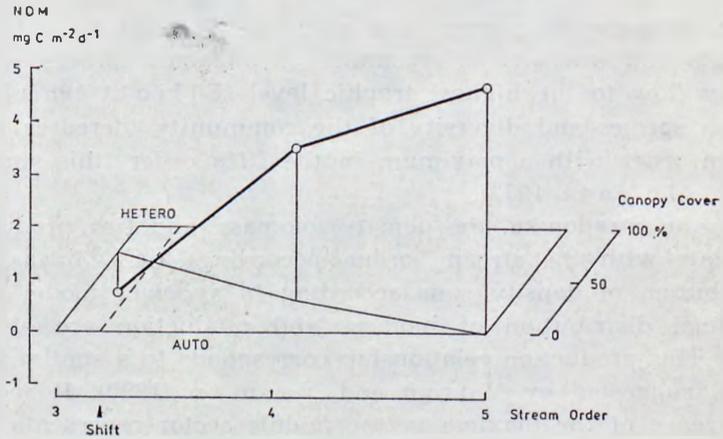


Fig. 6. Shift in the net daily metabolism (NDM) of the bottom community in relation to stream order and canopy cover

seems that the stream order does not organize the fish community while the longitudinal trends of changes are chiefly due to gradual shifts in the physico-chemical habitat (Matthews 1986).

Margalef (1968) suggested that stream ecosystems should be conceptualized as processes rather than as stable organisations. This concept and several new ones (RCC, RABC) imply a change of classic paradigm (Huet 1959) and the development of new methods (Fisher, Likens 1973, Hughes, Gammon 1987). Moreover, further detailed analyses are needed to quantify variability and to verify which factors

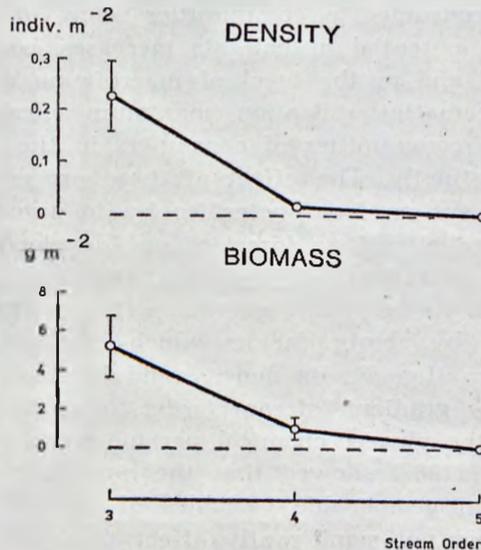


Fig. 7. Density and biomass of brown trout (*Salmo trutta m. fario*) in relation to the stream order

Table II. Correlations of brown trout density and biomass with habitat variables and physico-chemical parameters in the River Stradomka (levels of significance: \*\*\* —  $P < 0.001$ ; \*\* —  $P < 0.01$ ; \* —  $P < 0.05$ ; NS — non-significant)

Parameters	Brown trout	
	Density	Biomass
Habitat variables:		
gradient	0.73 ***	0.72 ***
width	NS	NS
depth	NS	NS
stream order	-0.65 **	-0.68 **
current velocity	NS	NS
distance from source	-0.65 **	-0.68 **
Physico-chemical parameters:		
temperature	-0.53 *	-0.60 **
pH	-0.61 **	-0.56 *
total hardness	-0.70 **	-0.71 **
conductivity	-0.63 **	-0.68 **
oxygen	NS	NS
calcium	-0.60 **	-0.66 **
N-NH <sub>4</sub>	NS	NS
P-PO <sub>4</sub>	NS	NS

affect fish populations in small rivers. This information will be essential in the understanding of the interactions between fish and their environment.

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## 6. Polish summary

Przebieg rozmieszczenia zespołów ryb w polskiej górskiej rzece a jego związki z abiotycznymi i biotycznymi czynnikami środowiska

W zlewni rzeki Stradomki (ryc. 1) ryby nie występowały w potokach 1- i 2-rzędowych ze względu na specyficzne warunki hydrologiczne i klimatyczne.

W odcinku 3-, 4- i 5-rzędowym (ryc. 2) liczba gatunków (ryc. 4) i różnorodność ryb były pozytywnie skorelowane z rzędowością i odległością od źródeł, negatywnie natomiast ze spadkiem rzeki. Na rycinie 3 zaprezentowano różnice (fizyko-chemiczne i biologiczne) między stanowiskami badań. Biomasa i produkcja całego zespołu ryb (z wyjątkiem liczby taksonów — tabela I) nie były związane z abiotyczną zmiennością siedlisk. Rozkład biomasy i produkcji ryb w stosunku do rzędowości przypomina funkcję wielomianu trzeciego stopnia (ryc. 5). Zagęszczenie i biomasa ryb były istotnie związane z chlorofilem *a* w peryfitonie (odpowiednio:  $r = 0,78$   $r = 0,57$ ). Wysokie stężenia wapnia ( $42-70 \text{ mg dm}^{-3}$ ) nie miały wpływu na biomasa i produkcję ichtiofauny w Stradomce. Zagęszczenie i biomasa pstrąga potokowego (*Salmo trutta m. fario*) spadały wraz ze wzrostem rzędowości (ryc. 6) i były skorelowane z czynnikami siedliskowymi i fizyczno-chemicznymi wody (tabela II). Między trzecim i czwartym rzędem potoków obserwowano dwie istotne zmiany specyfiki ekosystemu wodnego: wzrost koncentracji węgla organicznego w peryfitonie (ryc. 3) i zmiana rodzaju metabolizmu netto zespołów dennych z procesów hetero- do autotroficznych (ryc. 7). Powyższe procesy mogą tłumaczyć zmiany w strukturze jakościowej i ilościowej zespołów ryb. Na podstawie badań można postawić hipotezę, że zespół ryb (pstrąg potokowy, głowacz przegopletwy) w górnej części rzeki jest zdominowany przez czynniki abiotyczne, natomiast w dolnych partiach struktura i funkcje zespołu są pochodną czynników biotycznych, jak peryfiton i fauna denna.

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