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Tadeusz P e n c z a k[1], Luiz Carlos G o m e s[2, 3]

Impact of engineering on fish diversity and community structure in the Gwda River basin, north Poland

[1]Department of Ecology and Vertebrate Zoology, University of Łódż , 90-237 Łódź, 12/16 Banacha Str., Poland, e-mail: penczakt@biol.uni.lodz.pl

[2]Mississippi Cooperative Fish and Wildlife Research Unit. Post Office Box 9691, Mississippi State University, Mississippi 39762, USA

[3]Present address: Departamento de Biologia/Nupelia, Universidade Estadual de Maringá, Av. Colombo, 5790, Campus Universitário, CEP 87020-900, Maringá, PR Brazil

Abstract

Many mechanisms can determine the structure and functioning of fish assemblages. These were investigated for the Gwda River and its tributaries in Poland from samples collected during 1983–85 and 1995–97. The same 57 sites were sampled in both periods, using the same equipment (electric fishing) and team. Of the site characteristics examined only river engineering (canalization) explained the qualitative and quantitative changes in fish assemblages. In the two periods species richness was greater in the natural than in the canalized sites. Diversity was greater in natural sites in both periods but evenness was greater only in the second period. The position of dominants remained the same in both periods, but numbers of rare species declined in the last period. A greater abundance of fish was recorded in the first period in natural sites. There was some evidence that canalization had a deleterious effect on obligatory riverine species.
Key words: lowland river catchment, dams construction, bank revetment, fish diversity, fish assemblage, temporal variation

1. Introduction

Structure and functioning of ecological assemblages may be determined through a variety of mechanisms (Matthews *et al.* 1992; Hinch, Collins 1993; Taylor *et al.* 1996). Most common mechanisms are:

(1) resource limitation;
(2) environmental variability (limnological features and habitat structure);
(3) species interactions (predation) (Grossman *et al.* 1998).

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Most of these mechanisms may show temporal variations so that, over time, different fish assemblages may occur at the same location. Such an event could be investigated, because in the years 1983–85 quantitative fish samples were collected from 57 sites located in the Gwda River system (Koszaliński *et al.* 1989), and they were repeated in 1995–97 at exactly the same sites, retaining the full unification of sampling methods and site characteristics (Penczak *et al.* 1998).

The data was used to address the following questions:

(1) Do species richness, evenness and diversity indices show temporal variations and are they affected by habitat structure?

(2) Does species dominance show temporal variation and is it affected by habitat structure?

(3) Is habitat structure an organizational mechanism of fish assemblages?

2. Materials and methods

The Gwda River (147.5 km long, catchment area 4744 km^2) is the right side tributary of the Noteć River (The Odra River catchment). The middle Gwda and some of its tributaries run off from numerous glacial hills. As a result, the substratum comprises gravel and stones, which explains the presence of natural populations of salmonids. There are few towns and villages and 40% of the catchment is forest.

Twelve sites were located on the Gwda River and 45 on its tributaries (Fig. 1). These were the same for both sampling periods, except one (No. 12), which was drowned out by an artificially created reservoir in the second period. They were not evenly distributed through the catchment, largely because of problems of access. For each site the following parameters were recorded: distance from source (km), sampling date, mean width of channel (m), mean depth (m), substratum (proportion of silt, sand, gravel, stones), submerged plants, hiding places (fascine, fallen trees, overhanging willow branches, branches, roots, stones, litter), trees along banks, information on corridor structure (natural, meandering, regulated, impounded), pollution (frequently estimated only visually and by odour which was a measure of how much cattle manure was released to streams), and adjacent area (proportion of field arable land, forest, meadow, park). Further details are given by Koszaliński *et al.* (1989) and Penczak *et al.* (1998). The detailed characteristics are not repeated in this paper because with the one exception of regulation and impoundment, they did not explain temporal differences in fish assemblages.

Fish were caught from a boat or whilst wading, by two people, each operating anode dipnets. Full-wave rectified, pulsed DC current was taken from a 3 kW generator giving 230 V and 3–10 A output current. A single electric fishing at each site in accordance with Beklemishev's rule was done (Penczak 1967; Backiel, Penczak 1989) hence only relative abundance was obtained. The use of the same fishing equipment, team, effort, and borders of sites made these samples suitable for comparing differences in fish diversity and abundance with a lapse of time.

For the analysis, the sampled sites were categorized according to their characteristics. The two categories used were:

(a) canalized (indicating sites with conspicuous anthropogenic disturbances);

(b) natural (not disturbed).

This was done to evaluate habitat structure. For this, it was assumed that a canalized site is less structured than a natural habitat (fewer hiding places, less riparian vegetation, etc.). In 1983–85, 30% of the sites (17/57) were canalized. This percentage increased slightly to 40% (23/57) in the 1990s, but in the main river and its tributaries several dams were constructed in the 1990s, and only one with a fish-pass.

Species richness (S), evenness (E), and diversity index (H') were calculated annually, and by site categories for the two periods using PcOrd Multivariate Analysis (McCune, Mefford 1992). Whittaker Plots assessed species dominance. Species were ranked according to Log_{10} of the abundance. The variation of the most important species in the two study periods was assessed graphically.

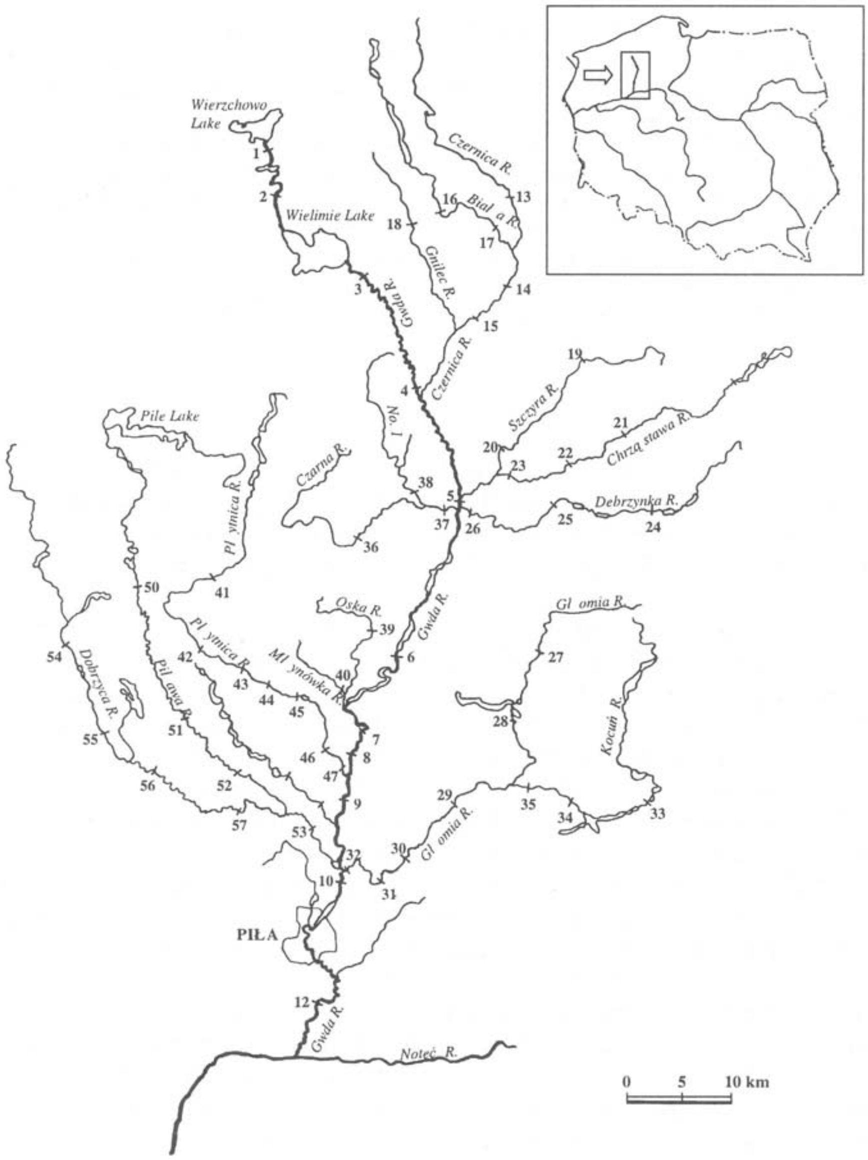


Fig. 1. The Gwda River basin with the 57 survey sites indicated

The species-environment data was first analyzed using Canonical Correspondence Analysis (CCA) (Ter Braak 1986). Despite the advantages of CCA as a direct gradient analysis (where species composition is directly related to measured variables) (Palmer 1993), the ordinations resulting from this analysis were not clear. This could be because species abundance is a linear or monotonic function of gradients (Palmer 1993) or because the variables used in the CCA were overwhelmed by the disrupting effects of engineering. To avoid this problem the authors first extracted from the species data the dominant pattern of variation in the community using

Detrended Correspondence Analysis (DCA) and then tried to relate this pattern to the environmental variables (Gauch 1982). For this, the sites were placed in two broad categories, namely those affected and those not affected by engineering, as this seemed to be the most important gradient identified by CCA.

DCA was used to ordinate the sites, using PcOrd (McCune, Mefford 1992). Three DCAs were performed, one with all data combined, in order to analyze the influence of site structure and year on fish assemblages. A two-way ANOVA was performed using SAS (proc GLM; SAS Institute 1996), with sites and years as factors. The dependent variable was the sampling scores obtained in the DCA. Two other DCAs were performed, for each sampling period separately, in order to assess temporal variation. A one-way ANOVA was performed using sites as a factor. This analysis was chosen because the DCA ordination graphs were sometimes difficult to interpret (too many sampling sites).

3. Results

Fish catch in 1983–85 comprised 2,807 individuals of 32 species (including lamprey) and in 1995–97 comprised 2,307 fish of 29 species (including lamprey). Numbers of fish collected in both periods were similar, probably because catches were conducted with the same unit of effort (CPUE), at the same sites, and by the same team.

In relation to the ecological characteristics, the following values were expected, for a given sample site, in 1983–85: Species richness (S) = 8, evenness (E) = 0.75, and diversity index (H') = 1.4 and in 1995–97, species richness (S) = 6, evenness (E) = 0.85, and diversity index (H') = 1.1. Species richness (S) was greater in the natural than in the canalized sites (Fig. 2) in the two periods of the study. Evenness did not vary in 1983–85, but was greater in natural sites in 1995–97. The diversity index was greater in the natural sites in both study periods.

Species dominance was very similar in both periods (Fig. 3). However, in the first period, a greater number of rare species were caught, and the total number of species was also greater. Species dominance was also very similar between the two categories of sites (Fig. 4). Overall abundance was greatest in the natural sites in 1983–85 but not in 1995–97.

The most important species (that contributed 90% of the catches) were different for the two sampling periods (Fig. 5). The most important changes between the years were a decrease in *Alburnus alburnus* and an increase in *Perca fluviatilis*. *Salmo trutta* m. *trutta* and *Leuciscus leuciscus* were only caught in the first period. *Salmo trutta* m. *fario* and *Pungitus pungitus* were important in the second period.

The results of the ordination were difficult to interpret, and they are not presented. The results of the two-way ANOVA (Table I) helped to better evaluate the ordination. Only the scores of the third axis showed significant differences between years. Sites were not an important mechanism for fish assemblage structure, which seemed very unusual. The results of the DCAs applied for the data set considering a year were useful to better explain what could be happening. For the first year, it is clear that site category was an important factor for structuring fish assemblages (Table II), but this was not important in the second period (Table III).

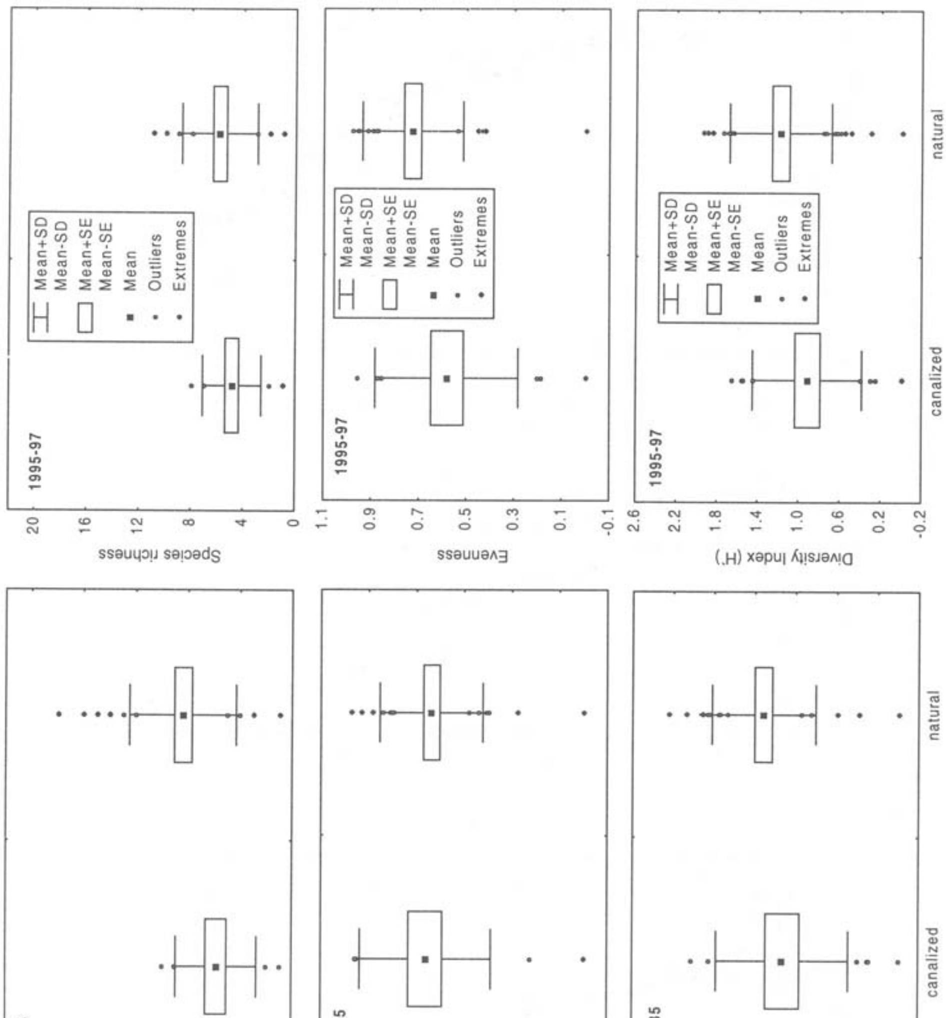


Fig. 2. Species richness (S), evenness (E), and diversity index (H') for canalized and natural sites in the Gwda River basin in 1983–85 and 1995–97

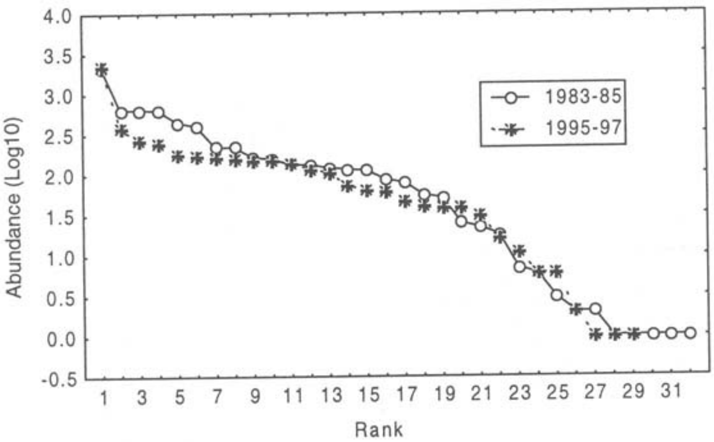
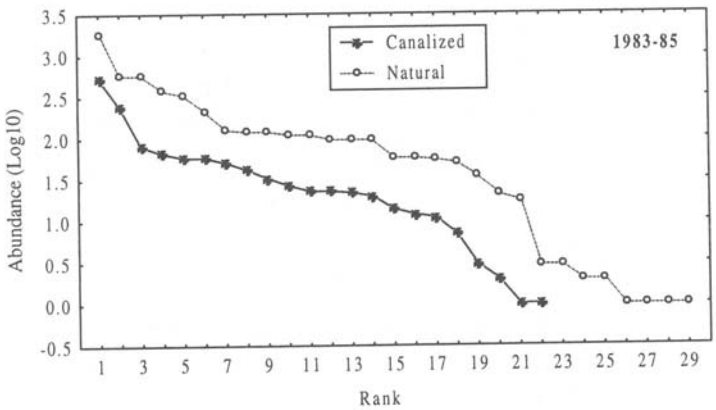


Fig. 3. Species dominance in the Gwda River basin in 1983–85 and 1995–97



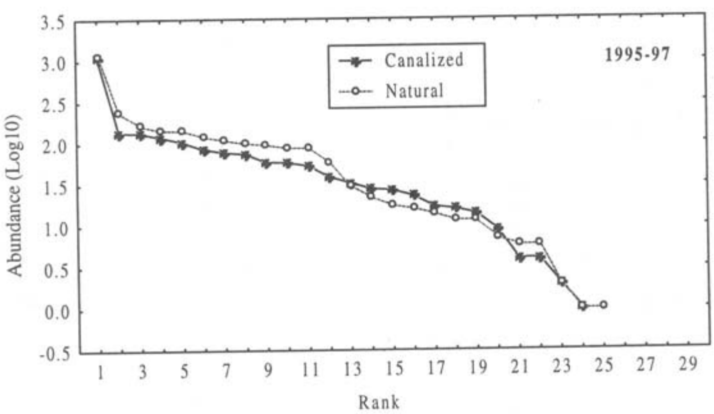


Fig. 4. Species dominance by site categories in the Gwda River basin in 1983–85 and 1995–97

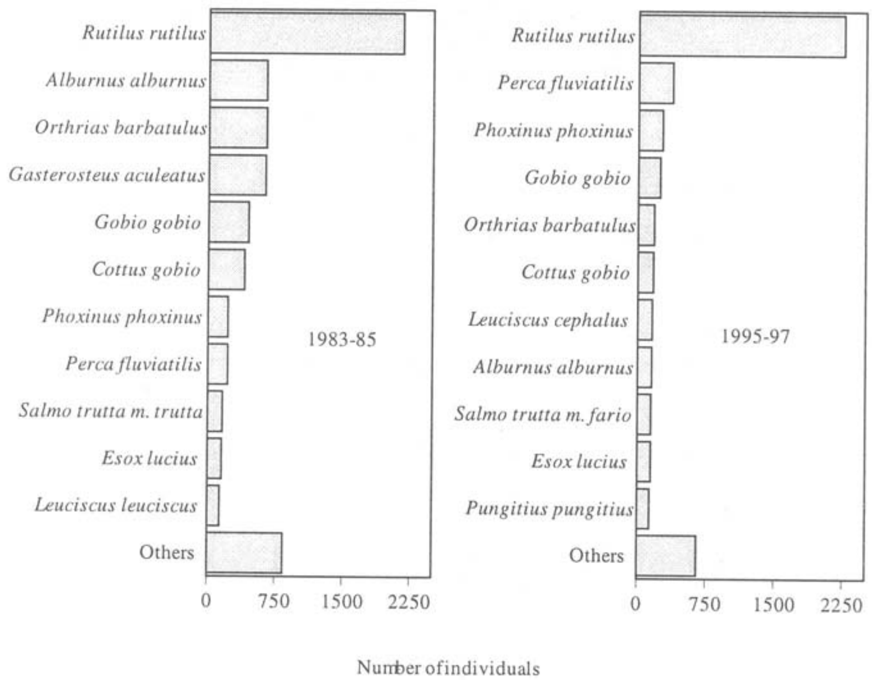


Fig. 5. The fish species caught most frequently in the Gwda River basin in 1983–85 and 1995–97

Table I. Results of the two-way ANOVA (sites and years were used as factors) applied on the scores of three axes obtained from Detrended Correspondence Analysis for the two sampling periods (significant value underlined)

Variable	Effect	G.L. effect	F	P
Axis 1	Sites	1	3.48	0.06
$\lambda = 0.511$	Years	1	1.64	0.20
	Interaction	1	1.71	0.19
Axis 2	Sites	1	0.17	0.68
$\lambda = 0.335$	Years	1	0.07	0.79
	Interaction	1	0.63	0.43
Axis 3	Sites	1	1.46	0.23
$\lambda = 0.215$	Years	1	24.50	<u>0.0001</u>
	Interaction	1	0.12	0.72

Table II. Results of the one-way ANOVA (sites used as factor) applied on the scores of the two axes obtained performing Detrended Correspondence Analysis, for the first period (1983–85) (significant value underlined)

Variable	Effect	G.L.effect	F	P
Axis 1 (λ= 0.486)	sites	1	8.07	<u>0.006</u>
Axis 2 (λ= 0.293)	sites	1	1.91	0.17

Table III. Results of the one-way ANOVA (sites used as factor) applied on the scores of the two axes obtained performing Detrended Correspondence Analysis, for the period (1995–97)

Variable	Effect	G.L.Effect	F	P
Axis 1 (λ= 0.660)	sites	1	0.03	0.86
Axis 2 (λ= 0.405)	sites	1	0.10	0.76

4. Discussion

Some problems were experienced when trying to unequivocally evaluate changes in the structure of fish assemblages which were under stress from canalization and dam construction. Grossman *et al.* (1990) recommend that "resource managers" and investigators synonymously evaluate anthropogenic stresses on the stream system, because even considerable impacts may be difficult to detect. Sometimes this is the case because "different analytical techniques may yield differing conclusions", but it may be that overlapping of stresses can confuse the proper interpretation. Long-term monitoring studies can be helpful in such situations (Spellerberg 1991; Penczak *et al.* 1998).

The problems exist presumably because whilst canalization in Poland has specific impacts during construction which are detrimental to fish (noise by machines, increase of silt in the water, removal of water and bankside vegetation and others), a few years later the same regulated sites can show ameliorated conditions for the existence of fish. Regulation of small rivers and streamlets consists of straightening banks, revetting them with fascine (dry osier branches), dredging to level the depth and increase the discharge capacity, and weir construction at intervals of several hundred metres. In medium and large rivers, eroding banks are revetted with limestone rocks or large stones; fascine and such construction is strengthened with wooden stakes. In large rivers, additional dyke construction takes place (Penczak, Mann 1993). Running water can soon partially wash out such constructions and provide refuges for fish (deep holes between rocks and stakes). It was in such places that large fish specimens occurred more often than in natural sections (Penczak, Mann 1993). This suggests, initially, canalized sites tend to be better structured. However, are 10 years enough to promote such changes? Another aspect may be that natural sites are not natural anymore, but have undergone gradual habitat degradation over time.

However, channel straightening and the resulting fluctuation in flow regime can reduce fish diversity and density, as has been observed in many other rivers also (Schlosser 1982; Hortle, Lake 1983; Mann 1988, 1998; Holcik 1990; Penczak, Mann 1993), with "angling species" being the first to be eliminated (Cowx *et al.* 1986). A uniform shallow habitat without pool refugia results in a simple community dominated by small, short living species and there is a considerable reduction of rare species (Schlosser 1987; Mann 1988). Decrease of diversity and density of fish in such new, shallow habitats can result in considerable mortality of fish during the winter (Schlosser 1987; Penczak *et al.* 1998).

Although rivers in Poland have not been changed to ones with a trapezoidal cross-section strengthened with tight cement slabs, as in some West European countries, nevertheless riparian trees and shrubs are removed during channel modification. Schlosser (1982), Armstrong (1983) and Penczak (1995) found that this can cause a major reduction in the majority of fish populations present. A really deleterious effect on riverine fish is exerted by reservoir dams installed without a fish-passes, especially those with hydroelectric plants (Petts 1984; Mann 1988, 1998; Orth, White 1993; Smith *et al.* 1993; Penczak *et al.* 1998). A dam is not the only barrier for migratory fish and obligatory riverine ones, but there is some evidence that even non-obligatory riverine species, such as *Rutilus rutilus*, tend to move upstream for spawning, and its 0+ group drift or swim downstream, enriching its populations (Zalewski *et al* 1990; Mann 1998). On the other hand, numerous reservoirs located along the river course make the environment more stable for some species with a consequential decrease in diversity indices but an increase in density, as was observed in this study.

The data obtained provided answers to the three questions posed at the outset and with some confidence because of the ten year gap between the two surveys. It is likely that a full exchange of generation took place and that the structure of the fish assemblages was influenced by new abiotic factors (Connel, Sousa 1983).

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