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UNIONID BIVALVES OF THE PILICA RIVER CATCHMENT AREA

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ABSTRACT: The 1995–1998 studies on the unionid fauna of the Pilica catchment area (C Poland) included 103 localities in the river, tributaries, floodplain water bodies and the dam reservoir on the river. As a result of qualitative and quantitative sampling six unionid species (one represented by two forms) were recorded: *Unio crassus* Philipsson, *U. tumidus* Philipsson, *U. pictorum* (Linnaeus), *Anodonta cygnea* f. *cygnea* (Linnaeus), *A. cygnea* f. *cellensis* (Schröter), *A. anatina* (Linnaeus) and *Pseudanodonta complanata* (Rossmässler). Three of them: *U. crassus, A. cygnea* f. *cygnea* and *P. complanata* were found to be rare. Dominance structure and density of unionids are discussed. Spatial distribution and abundance are analysed on the background of such ecological factors as character of bottom sediments, bottom configuration, vegetation, distance from shore, seston content as well as physico-chemical, hydrobiological and bacteriological water pollution. Ecological preferences of each species are described. Selected populations are characterised with respect to their age structure. Species which were abundantly represented are characterised with respect to their metric characters and sexual dimorphism, as well as effect of zebra mussel on their growth and condition.

KEY WORDS: unionid bivalves, distribution, dominance structure, density, spatial distribution, abundance, age structure, variability, morphometrics, condition, effect of zebra mussel, Pilica River

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INTRODUCTION

1.1. KNOWLEDGE OF THE UNIONIDS OF POLAND

The genera *Unio* and *Anodonta* are widespread bivalves, usually common in the lakes and rivers of Poland. The knowledge of their distribution, ecology and biology is still fragmentary, in spite of the over 100-year tradition of freshwater mollusc studies in Poland (PIECHOCKI 1996a).

Valuable data on the unionids of Poland can be found already in papers published at the end of the 19th and the beginning of the 20th c. Publications by BĄKOWSKI & ŁOMNICKI (1892), MERKEL (1894), POLIŃSKI (1917), GEYER (1919, 1927), MENTZEN (1925, 1926), BOETTGER (1926), FELIKSIAK (1930, 1931, 1933) and URBAŃSKI (1933, 1938) are especially noteworthy. After World War II there was a considerable intensification of the studies on the Unionidae. Fairly rich information on these bivalves may be found in both hydrobiological (e.g. OLSZEWSKI 1954, STAŃCZYKOWSKA 1960, GRZYBOWSKA 1965, WOLNOMIEJSKI 1965, GIZIŃSKI & PALIWODA 1972, KRZYŻANEK 1976, 1991, 1994, STAŃCZYKOWSKA et al. 1983, 1990, JURKIEWICZ-KARNKOWSKA 1989, DUSOGE et al. 1990, LEWANDOWSKI & STAŃCZYKOWSKA 1995) and faunistic publications, devoted to various parts of the country (e.g. KLIMOWICZ 1958, BERGER 1960, 1961, SOSZKA 1968, PIECHOCKI 1969a, 1972a, b, 1981, 1992, BERGER & DZIĘCZKOWSKI 1977, DYDUCH & FALNIOWSKI 1979, JURKIEWICZ-KARNKOWSKA & LEWANDOWSKI 1999).

Previous studies on the unionids of Poland dealt, among others, with an array of ecological problems, such as density, distribution, size-age structure, growth rate, biomass, production and filtration efficiency of selected populations. While many studies pertained to lacustrine populations (e.g. WIDUTO 1968, WIDUTO & KOMPOWSKI 1968, KRZYŻANEK 1970, 1976, 1977, 1986, 1991, 1994, LEWANDOWSKI & STAŃCZYKOWSKA 1975, KASPRZAK 1985, 1986, LEWANDOWSKI 1991), fluviatile unionids received much less attention. Besides the above-mentioned papers by MENTZEN (1925, 1926), there exist significant contributions by PIECHOCKI (1969a) and LEWANDOWSKI (1990), and smaller ones by ABRASZEWSKA-KOWALCZYK (1996, 1997), GRUŻEWSKI (1996) and JANICKI (1997).

Reproductive biology of some species of *Unio* and *Anodonta* was studied by PIECHOCKI (1969b, 1999), oogenesis and gonad histology in *A. anatina* – by DOMAGAŁA (1998).

Within the last few years the interest in unionids has extended to studies on the content of heavy metals and phosphorus in their shells and bodies (HŁYŃCZAK et al. 1997, KRÓLAK & KORYCIŃSKA 1997, JURKIEWICZ-KARNKOWSKA 1999, JURKIEWICZ-KARNKOWSKA & KRÓLAK 1999, KRÓLAK & STAŃCZYKOWSKA 1999), and to the effect of physico-chemical properties of water on some species (ZAJĄC 1998, 1999). Relations between unionids and other ecosystem components constitute a marginal but interesting topic (LEWANDOWSKI 1976, WOŁK 1979, ABRASZEWSKA-KOWALCZYK et al. 1999, PRZYBYLSKI & ABRASZEWSKA-KOWALCZYK 1999, ŚWIERCZYŃSKI 1999).

Taxonomic studies based on anatomical characters include papers by DYDUCH-FALNIOWSKA & KOZIOŁ (1989a, b), endangered species and their protection were discussed by e.g. DYDUCH-FALNIOWSKA (1992) and PIECHOCKI (1996b), problem of some introduced species – by PROTASOV et al. (1993), ZDANOWSKI (1996) and SINICYNA et al. (1997). Genetic studies on an introduced species – *Anodonta woodiana* – were carried out by SOROKA & SKOTARCZYK (1999).

For a long time URBAŃSKI's (1957) key to the molluscs of Poland remained the only means of identification of the Polish unionids, to be only recently replaced by a modern monograph of freshwater bivalves by PIECHOCKI & DYDUCH-FALNIOWSKA (1993), with comprehensive data on taxonomy, anatomy, biology and ecology, and keys to all the freshwater species of Poland.

It follows from the above review that ecological studies on unionids, though pertaining to a variety of problems, are fragmentary. There are no inventory-monitoring studies which would include diverse aquatic habitats, especially large rivers and floodplain water bodies. None of our main rivers has been studied in this respect; likewise, there were no studies on the effect of pollution on the viability and condition of these bivalves. Data on rare, protected and endangered species seem to require a verification. For this reason I have undertaken my studies on the unionids of the Pilica, one of the largest rivers in Poland.

Papers on large bivalves of lacustrine habitats occupy an important position in European literature (e.g. ZHADIN 1925, 1950, MODELL 1941, 1965, BJÖRK 1962, NEGUS 1966, TUDORANCEA & GRUIA 1968, WOLFF 1968, CASTAGNOLO et al. 1977, BLESS 1981, 1990, TÓTH & BÁBA 1981, BAUER 1983, 1987, 1992, 1994, FRANK et al. 1990, HOCHWALD & BAUER 1990, NAGEL 1992, NESEMANN 1993, 1994, KISS 1995, HOCHWALD 1997, KAPPES et al. 1997, ZETTLER 1997, 1998).

1.2. KNOWLEDGE OF AQUATIC FAUNA OF THE PILICA RIVER

The aquatic fauna of the Pilica River has been rather well studied; there exist papers dealing with the following taxa: sponges (KONOPACKA 1987), bryozoans (KONOPACKA & SZYMAŁKOWSKA 1980), oligochaetes (KAHL 1983, 1987), leeches (WIEDEŃSKA 1976), cladocerans (BRZOZOWSKA 1983), insects (MARKOWSKI 1974, JANOWSKA 1976, KITTEL 1976, 1977, 1980, JAŻDŻEWSKA 1976, 1979, OLSZEWSKI 1976, SICIŃSKI 1976, 1983), gastropods (PRESLER 1976), bivalves – reproduction (PIECHOCKI 1999) and benthofauna in general (JAŚKIEWICZ et al. 1976).

Because of the crucial importance of fishes for the development of unionid glochidia, the list should be supplemented with data on the ichthyofauna. Fishes of the Pilica River are well known due to wide-ranging monitoring and ecological studies (PENCZAK 1963, 1988, 1989, PENCZAK et al. 1995, 1996, PENCZAK & KRUK 1999, ZALEWSKI & SUMOROK 1984).

Because of the impounding role of the Sulejowski Reservoir and its effect on aquatic biocenoses, studies pertaining to this water body should be also listed: GALICKA (1986), ZALEWSKI et al. (1990, 1995), ZALEWSKI (1994, 1995, 1998), TARCZYŃSKA (2001).

1.3. OBJECTIVES OF THE STUDY

The main objectives of the study were:

1. Inventory of unionid species of the Pilica and reconstruction of their distribution along the river, in its major tributaries, floodplain water bodies and in the Sulejowski Reservoir;
2. Determining density, constancy and dominance of particular species in various types of habitats;
3. Determining habitat preferences and the effect of environmental factors on unionid populations;
4. Describing metric characters of unionids in various habitats.

I have also attempted to estimate the effect of environmental factors in the Pilica, among them indices of water quality (physico-chemical, hydrobiological, bacteriological), on unionid populations.

Because of the invasion of *Dreissena polymorpha* observed within the last few years in the Sulejowski Reservoir and the lower section of the Pilica, I have tried to evaluate the effect of the zebra mussel growing on unionid shells on their condition.

STUDY AREA

2.1. CHARACTERISTICS OF THE PILICA RIVER CATCHMENT AREA

The study area included the Pilica River with the Sulejowski Reservoir, some tributaries and selected water bodies of the floodplain (Fig. 1). The characteristics of the area was based on the data contained in KULMATYCKI (1936), FAGASIEWICZ (1963), PENCZAK (1963, 1989), KOSTROWICKI (1968), KRZYWAŃSKI (1976), KLECZKOWSKI & KOWALSKI (1978), KLATKA & ZIOMEK (1979), CZARNECKA (1983), KONOPACKA (1987), GALICKA (1996) and PENCZAK et al. (1996).

2.1.1. Geographical location

The Pilica – the eight largest river in Poland – is 342 km long. It is the largest left-bank tributary to the Vistula River to which it falls ca. 1 km below the village of Mniszew, at the 458th km of its course (94 m a.s.l.). The karstic sources of the Pilica are located in the eastern part of the Cracow-Częstochowa Upland, at 364 m a.s.l., ca. 3 km SW of the town Pilica. The surface area of the catchment area is 9,244.8 km^2, the total slope 0.7‰.

Having left the Cracow-Częstochowa Upland, the river flows northwards through Niecka Włoszczowska. Near Przedborze it enters an upland again, with the hills Wzgórza Radomszczańskie on the left and Pasmo Przedborsko-Małogoskie on the right side of the valley. The upland landscape disappears again near Ręczno, where Równina Piotrkowska plain begins. Below Sulejów, till its mouth, the Pilica runs eastwards. It flows in a typical lowland landscape, separating Wysoczyzna Rawska upland and Równina Warszawska plain from Równina Radomska and Równina Kozienicka plains.

2.1.2. Geological structure

The geological structure of the Pilica catchment area includes Mesosoic, Tertiary and Quaternary rocks. The oldest Triassic deposits, of the Świętokrzyskie Mts, occur in the eastern part of the catchment area. The largest area is occupied by Cretaceous rocks, extending from the western margin of Niecka Włoszczowska to Tomaszów Mazowiecki, and forming outcrops in many places. Tertiary deposits, in the form of silts and sands, are located in the lower section of the Pilica. Older rocks are found mainly in the southern and south-western parts of the area. To the north they sink below an increasingly thicker layer of Quaternary deposits which cover nearly the whole catchment area. As a result of Pleistocene glaciations, mainly the Odra glaciation, glacial sands, clays, ice-marginal silts and muds, sands and gravels of high river terraces, loess and dusty eolic deposits have accumulated.

2.1.3. Description of water courses and stagnant water bodies

Pilica

Semi-annual mean values and annual flow for various points of the Pilica and its tributaries are con-

Table 1. Mean semi-annual and annual flow in the Pilica (m^3s^{-1}) in 1991-1997: 1 – winter, 2 – summer, 3 – year

year	season/year	Szczekociny	Przedbórz	Sulejów	Spała	Nowe Miasto	Białobrzegi
1991	1	1.3	10.0	19.5	19.2	24.2	30.8
	2	1.1	6.2	10.6	14.7	17.2	22.9
	3	1.2	8.1	15.0	17.0	20.7	26.8
1992	1	1.6	11.6	20.4	21.3	25.5	33.3
	2	1.0	5.6	9.9	15.2	16.5	20.4
	3	1.3	8.7	15.1	18.2	21.0	26.8
1993	1	1.8	14.0	23.6	26.2	31.3	39.3
	2	1.2	8.4	14.8	15.0	16.3	21.7
	3	1.5	11.1	19.2	20.6	23.7	30.4
1994	1	1.6	15.3	26.6	32.4	37.3	49.2
	2	1.5	10.3	17.0	19.8	22.3	29.7
	3	1.6	12.8	21.7	26.0	29.7	39.3
1995	1	2.0	17.0	29.7	31.9	37.7	49.7
	2	1.4	9.0	13.9	16.8	19.3	26.1
	3	1.7	13.0	21.7	24.3	28.4	37.8
1996	1	1.5	10.8	16.9	20.2	23.7	32.7
	2	2.9	23.0	34.8	36.1	42.0	55.1
	3	2.2	16.9	25.9	28.2	32.9	43.9
1997	1	1.9	15.9	25.6	27.2	34.0	44.7
	2	3.0	22.4	34.1	38.2	46.9	58.4
	3	2.5	19.2	29.9	32.8	40.5	51.6

tained in Table 1. From its sources to Szczekociny, the Pilica has a character of a rapidly flowing stream, as a result of considerable unit slope above Szczekociny. The mean annual flow in Szczekociny in 1991 was 1.16 m^3s^{-1} and, through intermediate values in consecutive years, reached 2.49 m^3s^{-1} in 1997. In the upper section of the river the banks are regulated for ca. 25 km, often reinforced with spiling; the valley bottom is meliorated. The landscape is predominantly agricultural. Below Szczekociny, the Pilica receives a left-bank tributary Krztynia carrying loess deposits.

From Koniecpol the Pilica gradually becomes a slow-flowing river of the mean slope of 0.5‰, natural character and variable course, to reach the greatest variety of habitats in its section below Sulejów. There it receives large right-bank tributaries: Czarna Włoszczowska and Czarna Konecka, which is reflected in the values of mean annual flow. In Przedborze the flow ranged from 8.07 m^3s^{-1} in 1991 to 19.2 m^3s^{-1} in 1997. In Sulejów (below the outlet of Czarna Konecka) it was 15.0 m^3s^{-1} in 1991, increasing to 29.9 m^3s^{-1} in 1997. In the mid section of the river the valley slopes are raised. Over a considerable distance the river flows through woodlands. Below Sulejów it enters the Sulejowski Reservoir and, on the 170th km of its course, receives a left-bank, polluted tributary Luciąża. The flow speed gradually decreases, while the valley bottom becomes marshy. The dam is located 25 km below Sulejów in Smardzewice (196th km of the river course). Below Tomaszów the Pilica is smaller than in Sulejów, since a part of the water is drained to Łódz by a pipeline. Below Inowłódz (225th km), in the lower section, the valley widens to 3–5 km, the slope being 0.5‰. On its 256.3th km the Pilica receives the waters of Drzewiczka – its last large, right-bank tributary. In Białobrzegi (287 km) the mean annual flow was 26.8 m^3s^{-1} in 1991, increasing to 51.6 m^3s^{-1} in 1997. A characteristic feature of this river section is the difference between its right and left banks. The left bank is steep and high, densely populated and intensely used for agriculture, the right bank is gentle, terrace-like, in places humid or marshy, with riverine willow thickets.

Hydrologically (KULMATYCKI 1936), the river is divided in three sections: the upper from the sources to Koniecpol, the mid from Koniecpol to Tomaszów Mazowiecki, and the lower from Tomaszów Mazowiecki to the mouth. KITTEL (1976), based on his studies on Plecoptera, proposed a division in two sections: one ca. 70 km long, from the sources to Koniecpol, of varied course and relatively clear, and another, typically lowland and distinctly polluted, extending from Koniecpol to the river-mouth. The division was dictated by the biological barrier formed below Koniecpol, on a ca. 30 km section, as a result of the pollution load – sewage from the masonite factory in Koniecpol. Based on the criteria of river division according to fish provinces (STARMACH 1956, after PENCZAK 1963), the Pilica till the outlet of Drzewiczka can be included in the barbel province, and below Drzewiczka to its outlet to the Vistula – in the bream province. The division of the river which I adopted during my studies on the unionids essentially agrees with that proposed by KULMATYCKI (1936), the only difference being that I considered the effect of the dam reservoir on the lower section of the river and shifted the border between the mid and lower sections from Tomaszów Mazowiecki upstream, to the dam of the Sulejowski Reservoir in Smardzewice.

Tributaries

The unionid studies involved 12 out of the 49 tributaries to the Pilica: the left-bank tributaries included Krztynia (length 27 km) and Białka Lelowska (21 km), having their sources in the Cracow-Częstochowa Upland. Their bedrock is built of chalky marls covered with loess, resulting in a milky white suspension in their water. The Krztynia falls into the Pilica below Szczekociny on the 40th km, and the Białka Lelowska on the 65th km, below Koniecpol. Their studied sections had a natural character. Another left-bank tributary is Baryczka (20 km), a regulated river flowing across an agricultural area and falling into the Pilica below Maluszyn. A special role is played by left-bank tributaries Luciąża (48 km), Wolbórka (51 km), Czarna Bielina (23 km) and Piasecznica (24 km) – regulated, carrying waters from meliorated agricultural areas and factories, with a high pollution load. The Gać (18.2 km), a river of natural character flowing through the Spała forests, is only locally polluted with communal sewage from Spała.

Among right-bank tributaries, unionids were studied in the Zwlecza, Czarna Włoszczowska, Czarna Konecka and Drzewiczka. The Zwlecza (38 km) is a small, partly regulated and periodically polluted stream flowing in an agricultural landscape and falling into the Pilica below Maluszyn (88th km). The Czarna Włoszczowska (49 km) is a much meandering river of natural character and contributes relatively little polluted waters. Likewise, the Czarna Konecka (87 km) is a river of natural character. It falls into the Pilica on the 164th km, above Sulejów. In recent years its pollution has been observed to increase which is manifest, among others, in unfavourable qualitative and quantitative changes in its ichthyofauna (PENCZAK et al. 1995). The Drzewiczka (87 km) is the largest tributary to the Pilica which it joins at the level of Nowe Miasto (255.6 km). Except its mid, much polluted section, it flows in a natural bed and is clear. Long-term observations on its ichthyofauna indicate, however, a progressing degradation resulting probably from decrease in its water quality (PENCZAK et al. 1995).

Floodplain water bodies

On the floodplain of the Pilica there are numerous stagnant water bodies, commonly called oxbows, whose character, diversity of form, development and succession stages do not depart from those observed for such water bodies associated with other rivers, e.g. Grabia (PIECHOCKI 1969a). In the upper and mid course of the Pilica they originated most often by cutting off strongly bent meanders of the river, in the lower course they resulted, among others, from an intense accumulation of deposits and formation of islands dividing the river into branches. Such isolated branches turned into elongate oxbows, sometimes from several hundred metres to a few kilometres long, often parallel to the river bed. Specific types of aquatic habitats associated with the Pilica include the vaucluse complex Niebieskie Źródła near Tomaszów Mazowiecki and ponds formed on the tributaries, e.g. pond complex on the Gać River.

Sulejowski Reservoir

The Sulejowski Reservoir is located within Niecka Tomaszowska, between two gap sections of the Pilica, in Smardzewice and Sulejów. Almost all the reservoir and the surrounding area are covered with Quaternary deposits, reaching thickness of up to 10 m on the left and 30 m on the right shore near Barkowice.

The reservoir was formed in 1973, through damming the Pilica on the 196th km of its course (AMBROŻEWSKI 1984). Its main purpose was providing water to the city of Łódź, with the flow in the Pilica below the dam being undisturbed (AMBROŻEWSKI 1980). The Sulejowski Reservoir has a gutter-like shape, is 17 km long, of maximum width 2.0 km, maximum depth 11 m and mean depth 3.3 m. Its total capacity is 75 mln m^3 (AMBROŻEWSKI 1996). It can be divided in two parts: the upper one on the line Barkowice–Zarzęcin, of a river-pond character, and the lower, extending from Bronisławów to the dam, of a lacustrine character (GALICKA 1996). The orientation of the main axis of the reservoir – from SW to NE – is close to the prevailing direction of local winds, facilitating waving and water mixing, and causing continuous changes in the shoreline. These factors, and also large fluctuations of the water level (uncovering bottom over ca. 1,700 ha by 2–2.5 m in annual cycle) result in the aquatic and shore vegetation being poorly developed (OLACZEK & TRANDA 1990, GALICKA 1996, Report on the state of environment of the Łódź voivodeship in 1996). In the bottom deposits sand with an admixture of rock rubble and gravel prevails, with a layer of mud ranging in thickness from 7 to 27 cm. Thicker layers of deposits are found at the left shore and along the old bed of the Pilica. The deposits contain from 1.05 to 26.15% organic matter, as well as high quantities of phosphorus and nitrogen (GALICKA 1996).

2.2. WATER QUALITY IN THE PILICA, ITS SELECTED TRIBUTARIES AND THE SULEJOWSKI RESERVOIR

The Pilica is subject to a strong anthropopressure. This results from a combination of technical manipulations, existence of a large dam reservoir, canalisation, drainage of the valley through melioration, deforestation of the catchment area and water pollution. A detailed knowledge of water quality in the Pilica, its tributaries and the Sulejowski Reservoir is essential for correct interpretation of the data.

The assessment of water quality of the Pilica catchment area was based on materials of 1993–1997, kindly made available by the then Voivodeship Inspectorates for Environment Protection in Częstochowa, Kielce, Piotrków Trybunalski and Radom. I used also Reports on the state of environment in the voivodeships of Kielce in 1996, Łódź in 1996, 1997, Piotrków Trybunalski in 1996, Radom in 1995 and the Assessment of the water quality in rivers of the Radom voivodeship in 1997. The description of the assessment of water quality used by the State Inspection for Environment Protection (PIOŚ) is included in Material and Methods (p. 116).

Indices which served as the basis for assignment of sections of the Pilica and its tributaries to water quality classes (years 1993–1997) are listed in Table 2. Data on the water quality in the Pilica in 1993–1997 are contained in Table 3. Values of selected indices for inland surface waters of quality class III are shown in Table 4 (Decree of the Minister... 1991).

Pilica

In the first control points – from sampling site on the 36th km of the river course above Szczekociny, to the control point in Maluszyn (88 km) – the Pilica carried out-class water (96% control points of the State Inspection for Environment Protection within 5 years) (Tables 2, 3). The situation resulted mainly from the coli titre, high level of suspension, nitrite nitrogen, total phosphorus, and below Koniecpol (in 1995), also lead. The degree of pollution remained similar in subsequent years. Only as late as 1997 the sanitary condition improved in Maluszyn (class III). The main pollution sources in the area were: communal and industrial sewage from Szczekociny, Koniecpol and its masonite factory, Przedborze and Sulejów, as well as surface flow from cultivated fields. Besides the parameters exceeding the standards, the degree of pollution of the river was affected by 10 parameters, mainly physico-chemical (out of 40 parameters examined) with values corresponding to class III.

In the mid section of the river, from the outlet of Czarna Włoszczowska (control point Wymysłów, 94th km) to Sulejów (167th km), a considerable improvement in the water quality was observed in the analysed period (Tables 2, 3). Only in 35% control points of the State Inspection for Environment Protection during 5 years the water was found to be out-class, resulting from the high coli titre (incompletely processed communal sewage from sewage treatment plants in Przedborze and Sulejów). In 1996 the standards for copper and manganese were exceeded. Out of 40 studied parameters only nine did not correspond to the standards of water quality class II. A certain effect on the water quality in the mid course of the Pilica was exerted by pollutants carried by the tributaries Czarna Włoszczowska and Czarna Konecka, and especially Stobniczanka, as well as surface flow from the agriculturally used catchment area, whereas pure mining water discharged in large quantities by the lime factory in Sulejów had a positive effect.

Below the Sulejowski Reservoir, from the control point in Tomaszów Mazowiecki (203rd km) to the control point in Ostrówek (336th km) near the outlet, in its whole lower section the Pilica carried waters not corresponding to standards (100% control points of the State Inspection for Environment Protection during 5 years) (Tables 2, 3). This resulted mainly from a high content of chlorophyll a caused by phytoplankton drift; also the high coli titre was a disqualifying parameter (except 1997 when the sanitary state improved in the section from Nowe Miasto to Niemojewo). Sporadically, standards were exceeded by total phosphorus, nitrite nitrogen, zinc and copper, and high values of BOD_5 in the lower section of the river (from Białobrzegi to the mouth). The increased degree of pollution of the Pilica was additionally affected by ten parameters (out of 32) with values corresponding to class III.

The number of sewage discharge points in the lower Pilica is very high. One of the largest contributors is Tomaszów Mazowiecki, with a very high pollution load, of both communal and industrial sewage ("Wistom" factory). Two sewage treatment plants in Nowe Miasto, introducing incompletely processed communal sewage, should also be mentioned, as well as sewage from Tomczyce and Warka. An important source of pollution is also a right-bank tributary Drzewiczka, carrying sewage from the "Gerlach" factory and an inefficient sewage treatment plant in Drzewica, and the left-bank tributary Mogielanka, contributing, among others, untreated communal sewage from Mogielnica and partly treated tanning sewage.

Tributaries

The assessment of the water quality includes only those tributaries where unionids were studied.

Czarna Włoszczowska – in its lower section near Ciemiętniki it carried our-class water beacuse of exceeded coli titre (1994) and high values of COD-Mn and copper (1996–97). Six physico-chemical parameters corresponded to class III.

Czarna Konecka – control point at its outlet to the Pilica in Ostrów. Only in 1994 out-class water was

Table 2. Indices determining water quality class in 1993–1997 in the Pilica and its tributaries

Control point	1993	1994	1995	1996	1997
Pilica above Szczekociny (35.5 km)	**out-class**: nitrite N, coli titre; **III**: BOD_5, total P	**out-class**: total suspension, nitrite N; **III**: phosphates, total P, coli titre	**out-class**: total suspension, nitrite N; **III**: total P. coli titre	**out-class**: total suspension, nitrite N, coli titre; **III**: pH	**out-class**: nitrite N, total P, coli titre; **III**: total suspension
Pilica below Szczekociny (37.5 km)	**out-class**: coli titre; **III**: O_2, nitrite N	**out-clas**: nitrite N, coli titre; **III**: BOD_5, total suspension, total P, ether extract, saprobic seston	**out-class**: Pb, coli titre; **III**: total suspension, nitrite N, active anions, ether extract, saprobic seston	**out-class**: total P, coli titre; **III**: total suspension, nitrite N, active anions, saprobic seston	**out-class**: coli titre; **III**: total suspension, total P, saprobic seston
Pilica above Koniecpol (60 km)	**out-class**: nitrite N, coli titre; **III**: pH, total P, ether extract	**out-class**: nitrite N, coli titre; **III**: saprobic seston	**out-class**: total P, Pb; **III**: total suspension, total N, active anions	**out-class**: total suspension, total P; **III**: nitrite N, active anions, ether extract, coli titre	**out-class**: total P, coli titre; **III**: total suspension
Pilica below Koniecpol (65 km)	**out-class**: coli titre; **III**: ether extract	**out-class**: nitrite N; **III**: BOD_5	**out-class**: Pb; **III**: total suspension, active anions, coli titre	**out-class**: coli titre;	**out-class**: coli titre; **III**: total suspension
Pilica at Maluszyn (88 km)	**out-class**: coli titre; **III**: total suspension, nitrite N, total P	**out-class**: coli titre; **III**: nitrite N	**out-class**: total suspension, coli titre; **III**: nitrite nitrogen, total P	**out-class**: coli titre; **III**: COD-Mn, nitrite N	**III**: COD-Mn, total suspension, coli titre
Pilica at Wymysłów (94 km)	**III**: coli titre	**out-class**: coli titre; **III**: total suspension	**III**: saprobic seston, coli titre	**III**: COD-Mn, nitrite N, total Fe, coli titre	**III**: COD-Mn, total Fe, coli titre
Pilica below Przedbórz (124 km)	**out-class**: coli titre	**III**: coli titre	**III**: coli titre	**out-class**: Cu, coli titre	**out-class**: coli titre; **III**: COD-Mn, nitrite N
Pilica at Ostrów (160 km)	**III**: chlorophyll a, coli titre	**III**: coli titre	**III**: coli titre	**out-class**: Mn; **III**: COD-Mn, nitrite N, coli titre	**III**: coli titre
Pilica at Sulejów (167 km)	**III**: phenols, coli titre	**III**: suspension, coli titre	**III**: coli titre	COD-Mn, nitrite N, coli titre	**out-class**: coli titre; **III**: COD-Mn
Pilica at Tomaszów Mazowiecki (203 km)	**out-class**: chlorophyll a; **III**: total P	**out-class**: chlorophyll a; **III**: O_2, nitrite N, coli titre	**out-class**: chlorophyll a; **III**: O_2, nitrite N	**out-class**: chlorophyll a; **III**: total suspension, nitrite N, Mn	**out-class**: chlorophyll a; **III**: COD-Mn, nitrite N
Pilica at Spała (215 km) (active since 1996)				**out-class**: coli titre; **III**: chlorophyll a, nitrite N,	**out-class**: coli titre; **III**: COD-Mn, nitrite N
Pilica at Inowłódz (223 km)	**out-class**: chlorophyll a, coli titre; **III**: total P	**out-class**: chlorophyll a, coli titre; **III**: nitrite N	**out-class**: chlorophyll a, coli titre; **III**: nitrite N, total P	**out-class**: chlorophyll a, coli titre; **III**: nitrite N	**out-class**: chlorophyll a, coli titre; **III**: COD-Mn, nitrite N

Table 2. continued

Control point	1993	1994	1995	1996	1997
Pilica at Nowe Miasto (255.6 km)	**out-class**: (chlorophyll a not examined) coli titre;	**out-class**: chlorophyll a, coli titre; **III**: BOD_5, nitrite N	**out-class**: chlorophyll a, coli titre; **III**: nitrite N	**out-class**: chlorophyll a, coli titre; **III**: BOD_5, nitrite N, total P	**out-class**: chlorphyll a; **III**: BOD_5, coli titre
Pilica at Białobrzegi (289.8 km)	**out-class**: chlorophyll a, P, coli titre	**out-class**: chlorophyll a, Zn, Cu, coli titre; **III**: nitrite N	**out-class**: chlorophyll a; **III**: coli titre	**out-class**: chlorophyll a; **III**: coli titre	**out-class**: chlorophyll a; **III**: coli titre
Pilica at Niemojewice (315 km)	**out-class**: chlorophyll a, total P, coli titre; **III**: BOD_5, nitrite N, active anions	**out-class**: chlorophyll a, coli titre;	**out-class**: chlorophyll a, coli titre;	**out-class**: chlorophyll a, nitrite N, coli titre; **III**: total P	**out-class**: chlorophyll a; **III**: BOD_5, coli titre
Pilica at Ostrówek (336 km)	**out-class**: chlorophyll a, total P, coli titre; **III**: BOD_5, nitrite N	**out-class**: chlorophyll a; **III**: BOD_5, coli titre	**out-class**: chlorophyll a, coli titre	**out-class**: chlorophyll a, total P, coli titre; **III**: nitrite N, total Fe	**out-class**: chlorophyll a, coli titre; **III**: BOD_5, total P
Czarna Włoszczowska at Ciemiętniki	**III**: O_2, nitrite N, total P, coli titre	**out-class**: coli titre; **III**: COD-Mn	**III**: coli titre	**out-class**: COD-Mn, Cu; **III**: COD-Cr, nitrite N, total Fe, coli titre	**out-class**: COD-Mn; **III**: COD-Cr, Mn, coli titre
Czarna Konecka at Ostrów		**out-class**: Cu; **III**: coli titre		**III**: coli titre	
Luciąża at Przygłów	**out-class**: coli titre; **III**: nitrite N, total P	**out-class**: coli titre; **III**: nitrite N, total P	**III**: nitrite N, chlorophyll a	**out-class**: nitrite N; **III**: COD-Mn, total suspension	**out-class**: chlorophyll a, total suspension, nitrite N; **III**: COD-Mn, total P, coli titre
Wolbórka at Tomaszów Mazowiecki	**out-class**: nitrite N, total P, phosphates, coli titre; **III**: BOD_5	**out-class**: nitrite N, total P, phosphates, coli titre; **III**: total suspension, nitrite N	**out-class**: nitrite N, total P, phosphates, coli titre; **III**: BOD_5, nitrite N, chlorophyll a	**out-class**: nitrite N, total P, phosphates, coli titre; **III**: BOD_5, nitrite N, chlorophyll a	**out-class**: nitrite N, total P, phosphates, coli titre; **III**: BOD_5, nitrite N
Czarna Bielina at Tomaszów Mazowiecki	**out-class**: proper conductivity, chlorides, total dissolved substances, Na, Cu, coli titre; **III**: nitrite N, total P, chlorophyll a	**out-class**: proper conductivity, chlorides, total dissolved substances, Na, total P, coli titre; **III**: total suspension, nitrite N	**out-class**: proper conductivity, chlorides, total dissolved substances, Na, Pb, chlorophyll a; **III**: total suspension, nitrite N, nitrate N, total P	**out-class**: proper conductivity, chlorides, total dissolved substances, Na, total Fe, chlorophyll a, coli titre; **III**: total suspension, nitrite N	**out-class**: proper conductivity, chlorides, total dissolved substances, Na, nitrite N, chlorophyll a, coli titre; **III**: total P, Fe
Drzewiczka at Wola Załężna	**out-class**: nitrite N, total P, coli titre; **III**: phosphates	**out-class**: nitrite N, total P, phosphates, coli titre	**out-class**: total P, coli titre; **III**: total suspension, nitrite N, phosphates	**out-class**: nitrite N, coli titre; **III**: phosphates, total P, chlorophyll a	**out-class**: nitrite N, coli titre; **III**: total P, total Fe

Table 3. Water quality in the Pilica in 1993–1997

kilometers	1993	1994	1995	1996	1997
35.5	2	2	2	3	3
37.5	1	3	2	2	1
60	1	2	3	2	2
65	1	2	1	1	1
88	1	1	2	1	
94		1			1
124	1			2	1
160				1	1
167					1
Sulejowski Dam Reservoir					
203	1	1	1	1	1
215	x	x	x	1	2
223	2	2	2	2	2
255.6	2	2	2	2	1
289.8	3	4	1		1
315	3	2	2	3	1
336	3	1	2	3	2

(empty cell) class III quality of surface waters

Number of parameters exceeding the standard of water quality class III:

1

2

3

4

x missing data

Table 4. Selected parameters for class III quality of surface waters

Index	value
pH	6.0–9.0
total suspension	=50 mg/l
BOD_5	=12 mg O_2/l
COD	=30 mg O_2/l
dissolved O_2	=4 mg O_2/l
nitrite N	=0.06 mg N_{NO_2}/l
nitrate N	=15.0 mg N_{NO_3}/l
total N	=15.0 mg N/l
total P	=0.4 mg P/l
phosphates	=1.0 mg PO_4/l
proper conductivity	=1200 mS/cm
chlorides	=400 mg Cl/l
Na	=150 mg Na/l
Fe	=2.0 mg Fe/l
Mn	=0.8 mg Mn/l
Cu	=0.05 mg Cu/l
Pb	=0.05 mg Pb/l
anionic active susbtances	=1.0 mg/l
ether – extractable substances	=15.0 mg/l
chlorophyll a	=30 mg/l
faecal coli titre	=0.01 bac/ml

noted because of copper concentration exceeding the standard. In other years all the parameters, except coli titre, corresponded to class II.

Luciąża – control point in Przygłów near the Strawa outlet, just above outlet to the Pilica; the water was out-class because of coli titre in 1993–94 and a high level of nitrite nitrogen (1996). In 1997 an increased pollution, exceeding standard values, was noted resulting from chlorophyll a, total suspension and nitrite nitrogen.

The most polluted rivers were Wolbórka and its left-bank tributary Czarna Bielina with its tributary Piasecznica, carrying into the Pilica, near Tomaszów Mazowiecki (above the control point of the State Inspection for Environment Protection), an immense load of pollution which persisted during the five-year study period. In the Wolbórka the standard values were exceeded in the case of nitrite nitrogen, phosphates, total phosphorus and coli titre (100% control points within 5 years). The water quality was additionally deteriorated by discharge of sewage from an array of settlements, among others Piotrków Trybunalski through the Moszczanka. The Czarna Bielina carries also sewage from the synthetic fibre factory "Wistom" in Tomaszów Mazowiecki, resulting in exceeded standards for the following eight indices: proper conductivity, chlorides, dissolved substances, sodium, copper, total iron, coli titre, chlorophyll a. The Piasecznica receives sewage from Koluszki and Niawiadowo.

Gać – the water in the lowermost section in Spała was out-class in 1996–1997 because of the high coli titre. Concentrations of nitrite nitrogen and chlorophyll a corresponded to class III.

Drzewiczka – tested at the control point in Wola Załężna (45th km), receiving for years sewage from the factory of ceramic tiles in Opoczno and the municipal sewage treatment plant, in the analysed period carried out-class waters, because of the standards for nitrite nitrogen, total phosphorus, phosphates and coli titre.

Sulejowski Reservoir

Its water quality was the most affected by biogenic substances washed down from the surrounding fields, pollutants carried by the Pilica and Luciąża. The high degree of pollution is manifest in high, standard-exceeding concentrations of mineral nitrogen and electric conductivity (data of 1996–97) (Report on the state of environment in the Piotrków voivodeship in 1996 and Łódź voivodeship in 1997). High values of nitrogen and phosphorus favoured an intense development of phytoplankton, mainly diatoms and blue-green algae, which was reflected in high levels of chlorophyll a. Heavy metal content corresponded to water quality class I (GALICKA 1996).

2.3. LIST OF LOCALITIES AND GENERAL CHARACTERISTICS OF SELECTED TYPES OF AQUATIC HABITATS

In the list below consecutive localities are numbered with Arabic numerals; approximate distance from the source is given in parentheses, calculated based on a topographic map 1:50,000; the distribution of the localities is presented in Fig. 1.

Sources and upper section of the Pilica

1. (0 km) limnocrene sources of the Pilica, formed through filling of the outflow;
2. (5.5 km) Sławniów – a regulated section near the bridge, forming a system of cascades;
3. (12.5 km) Wola Libertowska – a regulated section at the bridge, banks spiled;
4. (18 km) Żarnowiec – a regulated section at the bridge;
5. (24 km) Małoszyce – a regulated section in an agricultural landscape;
6. (36.5 km) Szczekociny – river at the bridge, in the centre of the settlement, banks regulated, water polluted, bottom covered with garbage;
8. (51 km) Przyłęk – a natural river section at the bridge;
10. (67 km) Radoszewica – 1 km below Koniecpol, left, elevated bank, turbid water;
11. (76 km) Kuźnica Grodziska – a section at the mill, below the junction of river branches; river bed regulated, banks reinforced, water polluted.

This group of localities includes sections of the Pilica located in its upper and partly also its mid course. Their common characters are strong current, river bed regulated to a lesser or greater extent and a high degree of pollution. In all these sections the river flows among cultivated fields and carries little water. The substratum is mostly gravelly and stony, sometimes silty. For the most part there are no submerged plants, there are only sporadic tufts of *Caltha palustris* L., *Mentha aquatica* L., and *Potamogeton* sp.

Mid section of the Pilica

12. (80 km) Modła – a straightened, canalised river section;
13. (82 km) Pukarzew – a straightened river section, above the weir, current slow;
14. (86 km) Mosty – a natural, meandering river section below the fish ponds; the material was collected at the steep, left, undercut sandy shore; water containing suspension;
15. (88 km) Maluszyn – a natural, straight river section below the bridge, at the road Włoszczowa--Maluszyn; right bank marshy, with a wide belt of aquatic and reed-like vegetation;
18. (94 km) Sudzinek – a section at the ford, polluted with sewage from farms;
25. (119 km) Błota – a sandy meander at the right, steep bank;
26. (125 km) Dęba – a sandy bay at the left, steep bank of a meander, with muddy pits close to the shore;
27. (136 km) Faliszew – a lenithic river section above the mill, at the right bank;
29. (143.6 km) Placówka – a muddy, wide meander at the left bank at the level of the village;
30. (156 km) Przewóz – a muddy shoal in the forest;
31. (162 km) Komorniki Bielskie – a forested river section, at the left, slightly sloping bank; sampling sites: a) border of a reed belt and flat sandy bottom, b) shaded muddy bay below the preceding site;
38. (164 km) Kurnędz – a wide meander, the right, flat bank where the river comes close to the road Ręczno-Sulejów; sampling sites: a) sandy-gravelly--stony section, close to the shore, ca. 100 m long with moderate current; b) wide, muddy bay outside the main current, above the preceding site;
40. (165.5 km) Sulejów – the right branch of the river separated from the main current by an island, 0.5 km above the bridge;
41. (168 km) Sulejów – a slope of a sand bar bordered by reeds, at the level of the oxbow "Podklasztorze" (loc. 42), at the right bank, current slow;

The section comprises over 90 km of the purest part of the Pilica. Except for discharge of liquid manure in one place, during my studies I observed no other pollution sources. The river has a natural character; its width varies from 6–7 m (loc. 12) through 12–15 m (loc. 15) and 30 m on the meander in Kurnędz (loc. 38), to 35 m within the backwater of the reservoir below Sulejów. The depth ranges from ca. 0.30 m to ca. 2 m, being the greatest near high banks of the Pilica. During the studies I observed considerable fluctuations in depth, associated with varying precipitation. In the river bed sandy deposits prevailed. In the shore zone, especially where submerged or reed-like vegetation occurred, deposits of quaggy mud accumulated. On calmer sections of the river outside the main current and in depressions close to the shore the mud deposits reached the thickness of over 20 cm (loc. 38b), though this was only sporadically observed. In the mid section the degree of covering of the river bed with vegetation was rather high, especially in calm bays, meanders and lenithic sections, where the following plant species were the most frequent: *Acorus calamus* L., *Caltha palustris* L., *Ceratophylum demersum* L., *Elodea canadensis* Rich., *Equisetum limosum* L., *Fontinalis antipyretica* L., *Glyceria aquatica* (L.) Walb., *Mentha aquatica* L., *Microphyllum*

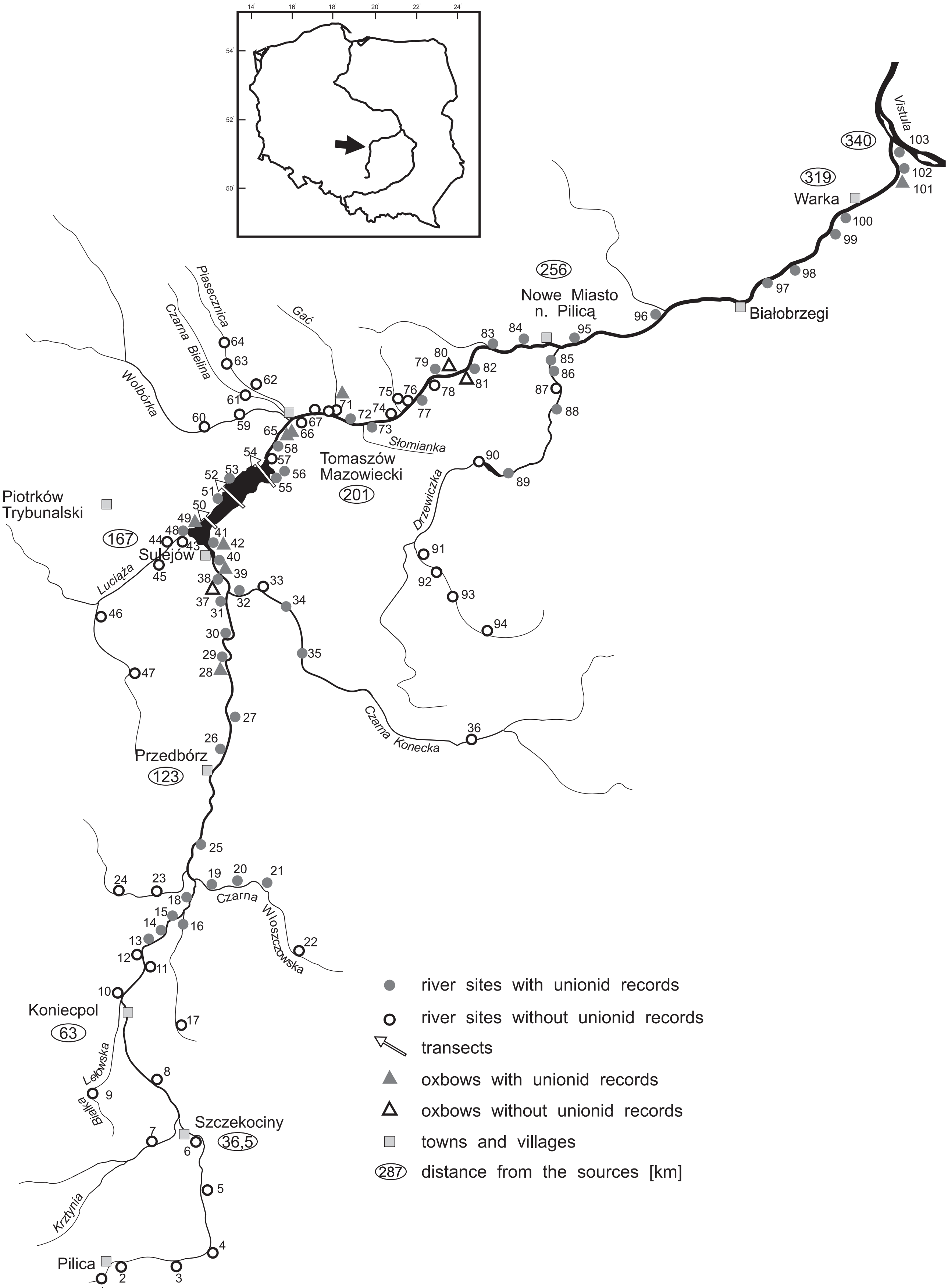

Fig. 1. Sampling localities in the Pilica catchment area

spicatum L., *Phragmites australis* (Cav.) Trin. ex Steud., *Potamogeton crispus* L., *P. lucens* L., *P. perfoliatus* L., *Rumex crispus* L., *R. hydrolaphatum* Huds., *R. obtusifolius* L., *Sagittaria sagittifolia* L., *Sparganium simplex* Huds., *Spirodela polyrrhiza* (L.) Schleid.

Lower section of the Pilica

57. (196 km) Smardzewice – a concreted river section 60 m wide, just below the dam of the Sulejowski Reservoir, current very slow, on bottom rock rubble;
58. (197 km) Smardzewice – a lothic river section at the end of the village;
67. (202 km) Tomaszów-Brzustówka – a river section at the level of water intake;
68. (208.5 km) Tomaszów Mazowiecki – a polluted river section, ca. 5 km below the town;
69. (215 km) Spała – river above the mouth of the Grabia, at the right, high and shaded bank, current quick;
72. (222.5 km) Teofilów – above the resort, where the river gets the closest to the road Tomaszów-Inowłódz; sampling sites: a) slope of river bed covered with a wide belt of *Typha* and ribbongrass, bottom covered with slimy mud of rotting smell; b) section 100 m above point a – bank muddy, reinforced with alder roots, in the main current bottom hard, covered with coarse gravel and stones;
73. (223 km) Inowłódz – a straightened river section just below the mouth of a right-bank tributary Słomianka;
74. (225 km) Inowłódz-Zakościele – a forest river section near a sandy island;
76. (233.5 km) at the level of nature reserve Żądłowice – a section polluted with agricultural sewage, at the left, marshy bank;
77. (234 km) Ponikła – a lothic section at the right, high bank below the village;
78. (236.5 km) Mysiakowiec – river on both sides of the bridge, on the road to Grotowice; right part of current polluted with liquid manure;
79. (239 km) Grotowice – a sandy meander, at the left, marshy bank, 0.5 km from the village;
82. (243) Gapinin – a meadow section of the river, at the right, high bank below the village;
83. (248 km) Domaniewice – a straightened river section above the bridge;
84. (253.1 km) Łęgonice – above the village, a beach on the right bank, water containing suspension;
95. (261 km) Gostomia – the left branch of the river above the bridge;
96. (277 km) Osuchów – a shallow fragment of the river above the bridge, at the slightly sloping right bank, at the level of pasture;
97. (294 km) Wincentów – a widened river section divided by an island, at the level of the village, water containing suspension, sampling sites: a) at the right, muddy and reed-covered bank at the level of the island; b) around a sandy island surrounded by tufts of ribbongrass, *Menyanthes* sp. and pondweed, in the current;
98. (301 km) Budy Michałowskie – a shallow at the left bank below the bridge, a section overgrown with sweet rush, at a distance from the village;
99. (303.5 km) Biała Góra – a deep bay at the right bank, outside the current, hard, sandy bottom with a wide belt of reed-like vegetation;
100. (315 km) Kępa Niemojewska – a reed-covered section below the undercut right bank at the level of the resort;
102. (328 km) Zagroby – the right, sloping bank densely covered with shrubs, at the level of the island, ca. 1 km from the village;
103. (340 km) Mniszewo – a bay at the right bank, below the bridge to Ostrówek, among willow thickets.

The lower section of the Pilica includes 144 km of the river course, from the dam in Smardzewice (196th km) to the mouth. The width of the river increases gradually, reaching 50 m at the level of Gapinin (site 82). In Wincentów (loc. 97) the Pilica is 100 m wide, and in its estuary section (loc. 103) it gets narrower again (40 m). The lower Pilica mostly carries out-class waters. The water in many places (e.g. locs 76, 78, 82, 97) is turbid, with a suspension of foam. Because of periodical discharge of water from the Sulejowski Reservoir, the river bed till 30 km below the dam is in many places devoid of lighter, sandy-muddy fractions of the deposit. Coarse-grained deposits prevail in this section, with a slight admixture of mud near the shore, especially in the belt of emerged vegetation. The depth of the river in the littoral ranges from 0.2 to 0.7 m in the shallows (locs 78, 79), the average depth being 0.4–0.6 m. In the main current the depth is most often 0.9–1.2 m. In the lower section of the Pilica macrophytes are scarce. The banks are covered with *Phragmites australis, Glyceria aquatica, Typha latifolia* L., *Sagittaria sagittifolia* L., *Menyanthes trifoliata* L. In the current, close to the banks, there are *Potamogeton natans, P. crispus* L. and sporadically *Elodea canadensis* Rich.

Tributaries

Krztynia

7. below Irządy – at the right, high bank at the level of the bridge, a regulated section, loess substratum;

Białka Lelowska

9. Lelów – a pure and natural section at the bridge in an oak-hornbeam forest, fed by numerous tributaries from the sources;

Zwlecza

16. Grajdołek – a naturally meandering stream near the mouth, polluted with liquid manure;
17. Brzozów – a regulated and spiled, shallow, clear stream with much vegetated banks, a meadow section above the village, current rapid;

Czarna Włoszczowska

19. Ciemiętniki – a section close to the mouth, with sloping, shaded banks at the bridge above the village (at the level of the ford); sandy-muddy substratum and single plants covered with a ferruginous deposit;
20. Januszewice – a large meander above the village, width 2–4 m, depth 0.1–0.2 m, bottom sandy, near the banks muddy with a coating of algae, no aquatic vegetation, water clear;
21. Komorniki – a meander of 3 m width, located 50 m below the bridge, banks shaded, high, bottom sandy-gravelly with detritus;
22. Żeleźnica Kielecka – a shallow section at the level of the village, banks rather high and spiled, river bed width 3–4 m, bottom sandy-gravelly, near banks muddy, covered with a film of filamentous bacteria, no aquatic vegetation;

Baryczka

23. Silniczka – a regulated section below the houses, with spiled banks, polluted with farm sewage;
24. Silnica – a regulated section among fields;

Czarna Konecka

32. Taraska – a river section close to the mouth, of gravelly and sandy bottom; in rapid current single tufts of *Elodea;*
33. Dąbrowa-on-the-Czarna – a sandy shallow in a meander below the bridge, at the left, sloping bank;
34. Rożenek – a meandering river section above the village, of very clear water, sandy-gravelly bottom and rapid current;
35. Skórkowice – a shallow, very pure section above the bridge; on submerged branches abundant sponge colonies;
36. Sielpia – a shallow section of moderately quick current, bordered with a belt of *Equisetum palustre*, flowing in a a marshy valley above the impounding reservoir on the Czarna;

Luciąża

43. Outlet to Pilica – a meandering section in a marshy valley; water with a considerable quantity of suspension;
44. Przygłów – a meadow section of rapid current, ca. 200 m below the bridge;
45. Włodzimierzów – a shaded fragment of a shallow, meandering river;
46. Łochyńsk – a regulated section flowing across a pasture, banks spiled;
47. Trzepnica – a regulated section flowing in a meliorated terrain, current very rapid, water polluted, of brown colour;

Wolbórka

59. Zawada – a natural, meadow section in a meander, width 2–3 m, depth 0.3–0.4 m, bottom gravelly--sandy, covered with large patches of *Elodea* and *Sparganium*, at banks reeds, current rapid;
60. Godaszewice – a regulated, spiled meadow section, width 4 m, depth 0.8–0.9 m, banks covered with reeds and stinging nettles, in current tufts of *Elodea* and *Sparganium*, bottom sandy-muddy, water turbid of manure smell;

Czarna Bielina

61. Zaborów – a regulated, narrow canal of sandy bottom and rapid current, water turbid;

Piasecznica

62. Zaborów – a regulated, polluted mouth section, devoid of aquatic vegetation;
63. Ujazd – a shallow, regulated section of rapid current;
64. Niewiadów – a shallow, regulated and polluted canal, bottom covered with gravel and fine stones, current rapid;

Gać

65. Spała – a regulated, fairly deep mouth section below the bridge, banks covered with sedges and goat's beard, in current pondweed, water turbid;

Drzewiczka

85. Borowiec – a straightened, mouth section 5–10 m wide, just at the road to Nowe Miasto (at the level of ponds); banks high, with alders; depth in current ca. 0.3 m (in pits near banks to 0.8 m), bottom sandy-muddy, devoid of macrophytes;
86. Wólka Ligęzowska – a meadow, natural meander overgrown with macrophytes;
87. Żarki – polluted river at the level of the village, near the road;
88. Wysokiń – a fragment of current at the right, reed--overgrown bank, 0.8–0.9 m deep, below the bridge;
89. Drzewica – a shallow section among the town houses, below the "Gerlach" factory;
90. Dąbrówka – a straightened section below Drzewica, width 10 m, depth 0.2–0.3 m, banks reed-covered, current moderate, sandy bottom;
91. Ogonowice – a shaded meadow section of sandy--gravelly bottom, at banks single tufts of *Elodea*, water with slight manure smell, width 6 m, depth 0.3–0.6 m;
92. Sitowa – a meandering meadow section, with single alders at the bank, width 4–5 m, depth 0.2–0.4 m, bottom sandy with large tufts of *Elodea* and filamentous algae;
93. Petrykozy – polluted river at the level of the village, banks shaded, width 6–7 m, depth 0.3–0.5 m, bottom gravelly-stony with single tufts of *Elodea;*
94. Morzywół – a meandering meadow section above the village, width 2–4 m, depth 0.3–0.5 m, banks high, bottom sandy-clayey;

The sites in this group are small and medium-sized streams and rivers, from a few to several dozen kilometres long, flowing mainly through an agricultural landscape. Their current is usually rapid, their bottom sandy or sandy-gravelly, and aquatic macrophytes are scarce. The depth ranges from 0.2 to 0.5 m, being somewhat greater at their mouth sections. The mean widths vary from 1 to 6 m. Two groups can be distinguished among these water courses: 1 – regulated and polluted, flowing through built up or cultivated areas: Baryczka, Luciąża, Wolbórka, Czarna Bielina, Piasecznica; 2 – pure, or only slightly polluted rivers of natural character, partly flowing across wooded areas: Białka Lelowska, Czarna Włoszczowska, Czarna Konecka, Gać (fragments), Drzewiczka.

Floodplain water bodies

28. Placówka (Fig. 2e), the first of a row of ponds formed on an arch-like oxbow on the left bank of the Pilica. The length of the reservoir connected with the river is 35 m; its shores are covered by clumps of reed-like vegetation, in the water numerous tufts of *Sagittaria* and white water-lilies. Sampling sites: a) shallow, sandy bottom just above the connection with the river; b) muddy bottom in the mid part of the oxbow, depth 0.80–1.00 m; c) clayey-muddy bank on the opposite end of the reservoir;
37. Kurnędz (Fig. 2c) – a deep oxbow, ca. 300 m long, cut off from the Pilica, located on a marshy meadow, distance from the river ca. 100 m. Bivalves were sampled in two extremely distant parts of the oxbow;
39. Taraska (Fig. 2i) – an oxbow disappearing in places, connected to the Pilica, ca 1 km long and 3–10 m wide; on the right bank of the river, above Sulejów. Five sampling sites were selected along the oxbow, point a being closest to the junction with the river, consecutive points being ca. 150–200 m apart;
42. Podklasztorze (Fig. 2f) – a right-bank oxbow, divided by a dyke, crescent-shaped, overgrown, total length ca. 200 m. Bivalves were sampled in the part of the oxbow connected to the Pilica, ca. 30 m long, in five points: a, b, c – along the left, willow-covered shore, depth 1.1–0.7 m, d – a shallow, sandy fragment with reed-like vegetation at the level of the dyke; e – a sand bar at the junction with the river. A detailed map of the oxbow, with sampling sites, is shown in Figure 19 (p. 136);
49. Barkowice Mokre (Fig. 2g) – a part of the Sulejowski Reservoir close to the shore, separated by an island, 370 m long and of only slight flow. Six transverse transects were sampled there (a–f) (Fig. 20, p. 137);
65. "Niebieskie Źródła" (Fig. 2h) – outflow canals and margins of the vaucluses in the nature reserve "Niebieskie Źródła";
66. Tomaszów-Brzustówka (Fig. 2h) – a small, oval oxbow on the right bank of the Pilica, separated from the river by a low embankment;
70. Konewka – an emptied pond on the Gać River;
80. Grotowice (Fig. 2a): a – a marshy, cut-off river branch on the left bank of the Pilica, overgrown with reed and *Stratiotes*; b – a very muddy oxbow, connected with the river, 60 m long, in a forest above Grotowice;
81. Gapinin (Fig. 2b) – an oval, strongly overgrown oxbow periodically connected with the Pilica, on the right bank of the river, 30 m long;
101. Zagroby (Fig. 2d) – a dead river branch, over 2 km long, in permanent contact with the Pilica. Samples were taken in three clearly different fragments of the oxbow: a) a much vegetated section, b) a section fed with stream waters, c) a depression;

All the oxbows in the mid section of the Pilica (locs 28, 37, 39, 42) and some of those located in the lower section (locs 80a, b, 81, 66) can be classified as typical oxbows, resulting from cutting off the river meanders. Locality 49 is an example of river branch formation through accumulation of river deposits and a resulting island. Locality 101 (Zagroby) is a dead river branch. Some of the studied water bodies, from several dozen to several hundred metres long, and a few to about a dozen metres wide have preserved their crescentic, elongate shape of meanders with their arms directed towards the river bed. Others resemble small, sometimes deep ponds. In young reservoirs, connected with the river, the bottom is often sandy, with a small quantity of muddy deposits (locs 39, 42). In older, more isolated water bodies, layers of mud or mud and detritus accumulate, especially in their parts remote from the river bed and also in their central, deeper parts (locs 80, 81, 101). The water bodies are vegetated to varying degree. In deeper oxbows there grow *Batrachium trichophyllium* (Chaix) van den Bosche, *Ceratophyllum demersum* L., *Myriophyllum spicatum* L., *Potamogeton natans* L., *Stratiotes aloides* L. In shallower parts there are clumps of *Nuphar luteum* (L.) Sm., *Nymphaea alba* L., *Sagittaria sagittifolia*, *Hydrocharis morsus-ranae* L., *Elodea canadensis* Rich., *Lemna minor* L. and *L. trisulca* L. The banks are covered by reed-like vegetation: *Acorus calamus* L., *Carex* sp., *Iris pseudacorus* L., *Phalaris arundinacea* L., *Phragmites australis*, *Rumex* sp., *Schoenoplectus lacustris* (L.) Pallas.

Sulejowski Reservoir

The location of sampling sites in the Sulejowski Reservoir is shown in Figure 17 (p. 135).

Transverse transects

50. Transect I – the upper, shallow part of the reservoir (backwater zone), at the level of Barkowice. In the transect 1,500 m long 7 sampling sites were selected, maximum depth 3 m, bottom sediments sandy, in the river bed muddy. Bottom on the eastern shore covered with fallen trees;

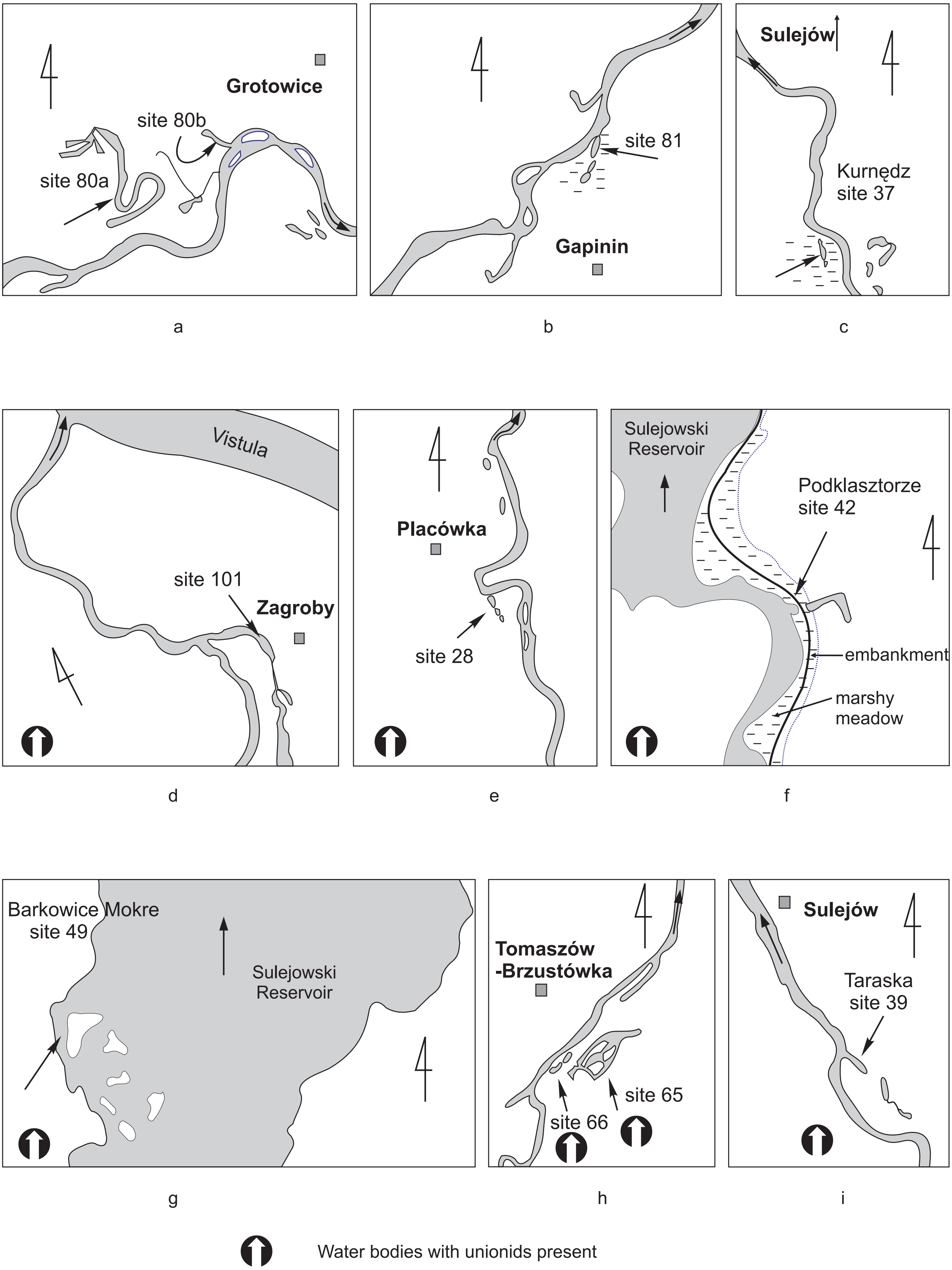

Fig. 2. Location of the examined water bodies of the Pilica floodplain

52. Transect II – the mid part of the reservoir, from the bay called "Zatoka Dębów" to the village Bronisławów on the opposite shore (intake of water for the city of Łódź). Transect length ca. 1,500 m (14 sampling sites), maximum depth 6.5 m, bottom deposits sandy, in deeper parts of the reservoir muddy, at the eastern shore with a layer of detritus. Steep slope of the former river bed covered with tree trunks and roots;
54. Transect III – the lower part of the reservoir, from the stream mouth at the level of Tresta Rządowa to the opposite shore in Swolszowice Małe. Transect length ca. 2,000 m (10 sampling sites), depth 8 m, bottom deposits in shallow parts sandy, in deeper parts muddy.

Shore localities

48. (178 km) Murowaniec – Pilica below the mouth of Luciąża, backwater zone of the Sulejowski Reservoir, current slow, sample taken from the steep slope at the left bank;
51a. Barkowice Mokre – a promontory at the end of the village, at the left shore of the reservoir, shallow (0–0.5 m), sandy bottom with a thin mud layer;
51b. Barkowice – flat, uncovered bottom at the level of the school;
53a. Reservoir below Bronisławów – a sandy shallow at the level of the islands, 30 m away from the shore;
53b. Adamów – the left shore of the reservoir, bay at the level of the camping site in the yacht harbour, muddy bottom covered with sandy deposits. At sampling site depth 0.5–0.7 m;
55. Tresta Rządowa – a sandy bay at the right shore, in an estuary section of a stream. Bottom sandy and coarse gravelly, in the water column and on bottom dense accumulations of blue-green algae;
56a. Smardzewice – a fragment of the reservoir at the right shore, 200 m from the dam. Sandy bottom with rubble and gravel, covered with a thin mud layer, in water column blue-green algae;
56b. Smardzewice – reservoir at the concrete bordering of the dam, 20 m from hydrotechnical equipment.

MATERIAL AND METHODS

3.1. FIELD STUDIES

The field studies on the unionids of the Pilica catchment area were carried out in 1995–1998, from May till October. They included the river from its sources to the mouth, 12 selected tributaries, 12 water bodies of the flooplain and the Sulejowski Reservoir (Fig. 1).

The total number of localities was 103, with 156 sampling sites: 46 localities on the Pilica (50 sampling sites), 37 in the tributaries, 12 (30) on the floodplain and 8 (39) in the Sulejowski Reservoir where, besides five localities situated close to the shore (each divided into parts a and b), three transverse transects were made in the upper (loc. 50), mid (loc. 52) and lower (loc. 54) parts of the reservoir. The transects included 7, 14 and 10 sampling sites, respectively (see Fig. 17, p. 135). Names of the localities are names of the nearest settlement.

Qualitative and quantitative samples were taken once at each site, the shore zone of the river and stagnant water bodies being the first to be examined. In case of negative results, I repeated the search next year. In order to obtain qualitative materials, in shallow and easily accessible places I collected bivalves by hand. In deeper places I used a net or a dredge adapted to bivalve collecting. The cutting edge of the dredge (designed by Mr MAREK ŚWIERCZYŃSKI, M. Sc.), 20 cm wide, was serrated. Materials from the Sulejowski Reservoir (the region of the dam and the transects) were collected by divers.

Quantitative samples were taken with a metal frame 0.5 × 0.5 m (surface area 0.25 m^2). The frame was thrown randomly on the bottom several (3–5) times, and the bivalves found inside it were identified and counted. The data obtained were recalculated to 1 m^2 bottom surface. Parallelly, or in case of negative results, I used the "time" method (semi-quantitative sampling). In sites where the samples taken with the frame were positive, I searched the bottom during 15 minutes. In case of negative quantitative samples the search duration was extended up to 1 hr. If during that time I found no living unionids, I discontinued the search. In order to unify the data, all the results from all the sites were recalculated to 15 min periods (hence some fractional values in the tables).

In most sites I took samples of bottom sediments for granulometric analysis. In the spring, summer, autumn and winter of 1997 I took also water samples for seston determination in three localities in the mid section of the Pilica (localities 15, 29, 38), two localities in the lower section (57, 82) and in the Sulejowski Reservoir in Smardzewice (56). On each occasion 10 l water were taken 1–2 m away from the shore, where the depth exceeded 1 m.

3.2. LABORATORY STUDIES

The bivalves brought from the field were measured and weighed, in order to obtain data for morphometric analyses. Shells were measured with a slide calliper, accuracy 0.1 mm. The following para-

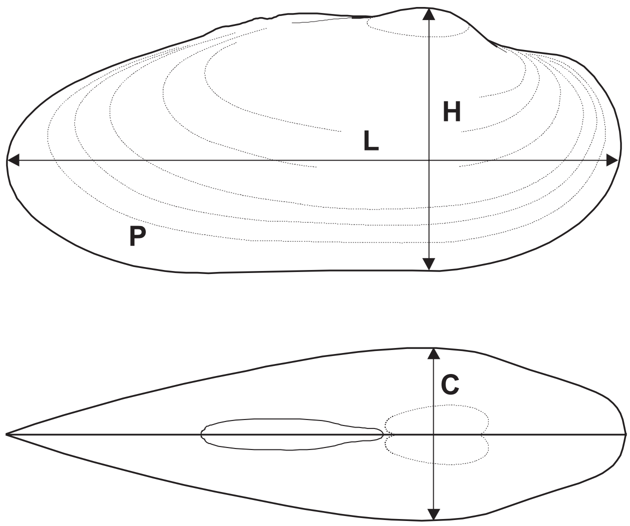

Fig. 3. Shell measurements: L – length, H – height, C – convexity (thickness); P – annual growth ring

meters were considered: length (L), height (H) and convexity (width; C) of the shell (Fig. 3). The height was measured at umbones; the convexity corresponded always to the greatest width of the specimen, which was usually located slightly posterior to the umbones. The abbreviations of shell parameters are used further in the text and tables.

After measuring, all the specimens were weighed with electronic balance SARTORIUS-BA2100S, accuracy 0.01 g. After a careful separation of soft parts (visceral sac with mantle and all fragments of muscles) and drying with blotting paper, body and shell were weighed separately, resulting in shell mass and wet mass of soft parts (further called wet body mass).

The age of the bivalves was determined based on the number of the so called annual growth rings (P) on the shell (Fig. 3). The method was presented among others by ZHADIN (1938), CROWLEY (1957) and PIECHOCKI & DYDUCH-FALNIOWSKA (1993).

The dissected specimens were used to determine sex. For this purpose, after opening the shell, the body covers were cut at the base of the foot and a part of the gonad was removed with a pipette. The presence of spermatozoa or eggs was verified under the microscope (100×). The state and contents of the outer demibranchs of females were also examined. When the demibranchs were "swollen", they were opened with a scalpel and the contents squeezed out of them was examined under stereomicroscope (60×) in search of cleaving embryos or glochidia. The presence of the zebra mussel (*Dreissena polymorpha*) on the shells was also recorded.

In order to ascertain preferences towards various kinds of bottom deposits, granulometric analysis was carried out, and the content of organic matter determined. In places of bivalve occurrence 500 cm^3 of the deposit were taken with sediment grab. In the laboratory the deposit was dried at 105°C during 24 hrs, divided into fractions with a column of differential sieves, mesh size: >4, >2, >1, >0.5, >0.25, >0.125, >0.063 and <0.063 mm. Then each fraction was weighed and combusted at 550°C to constant weight (3.5 hrs). A repeated weighing of the deposit made it possible to ascertain the weight proportion of organic matter, as the weight difference before and after combustion.

Because of the filtratory mode of feeding of bivalves, the seston content in the water may be a factor determining the unionid occurrence and abundance. Below the Sulejowski Reservoir the quantity of seston carried by the river decreases considerably, since a large part of suspension is retained in the reservoir. This is favoured by the long time of water retention, amounting to ca. 30 days (GALICKA 1996). In order to compare the seston content in the river – above the reservoir, in the lower part of the reservoir and below the dam – I selected six sites were the seston content was analysed (Table 10, p. 140). Water samples of 10 l were filtered through qualitative filters Filtrax 389, using vacuum pump. The resulting filtrate was dried at 65°C during 48 hrs, weighed with electronic balance, accuracy 0.0001 g, combusted at 550°C to constant weight, and weighed again to determine the content of organic matter.

To estimate the water quality in the Pilica, its tributaries and the Sulejowski Reservoir I used results of analyses of 1993–1997, made available by the Voivodeship Inspectorates of Environment Protection in Częstochowa, Kielce, Piotrków Trybunalski and Radomsko. Water samples for laboratory analysis of physico-chemical, bacteriological and hydrobiological pollutants were taken by these Inspectorates twice a month from sections of the Pilica and its tributaries located in the respective voivodeship. I had at my disposal results of analyses from a total of 16 control-measurement points distributed along the course of the Pilica and in the tributaries. In the discussed area 3–40 parameters were applied. The list of basic indices of pollution of inland surface waters, with standards for class III waters, is shown in Table 4. Exceeding this values means out-class water.

The results of analyses made available to me were calculated – in accordance with the recommendations of the State Inspectorate for Environment Protection (GOŁĘBIOWSKA et al. 1994) – with the method of characteristic concentrations which consists in calculating arithmetic mean of the two most unfavourable values during the monitored period, the result departing from the second highest by over 200% being rejected. I used these data for the statistical analysis, while when describing the water quality in the studied water courses I used the pre-determined quality classes. For statistical analysis I selected water quality indices which were measured in all the control points during five years and which reached the highest proportion of standard-exceeding and quality class III values.

For the characteristics of habitats I used data on mean semi-annual and annual flow of the years 1991–1997, made available by the Institute of Meteorology and Water Management, for 7 sites in the Pilica (Table 1).

3.3. DATA ANALYSIS

3.3.1. Variables

The analysed variables were specified as follows:

Type of aquatic habitat. Based on the observations on the occurrence of bivalves I grouped the localities in six classes:

0. sources and upper section of the Pilica – including the initial section of the river, to the 76th km (locality 2);
1. mid Pilica – from the first appearance of unionids (locality 13) to the backwater zone of the Sulejowski Reservoir (locality 40);
2. lower Pilica – river localities below the Sulejowski Reservoir to the outlet to the Vistula;
3. tributaries (all the examined tributaries) where unionids were found;
4. oxbows – water bodies of the floodplain where living unionids were found, except the reserve Niebieskie Źródła;
5. Sulejowski Reservoir, including the shore localities and the three transverse transects (localities 50–56) from the backwater zone to the dam.

In ecological considerations contained in this paper and in statistical tests the terms describing habitat types correspond to those listed above.

Species. All the forms and species of unionids recorded from the study area were included in the analyses: *Unio pictorum, U. tumidus, U. crassus, Anodonta anatina, A. cygnea* f. *cygnea, A. cygnea* f. *cellensis, Pseudanodonta complanata*.

Density is the number of unionid individuals per 1 m^2 of bottom surface (Nm^{-2}).

Relative abundance is the number of individuals collected in a unit time (Nt^{-1}).

Biomass. For each unionid species it is the sum of wet body mass and shell mass per 1 m^2. It was calculated as the so called mean biomass for each of the habitat types distinguished above (except tributaries).

Metric and non-metric characters of the bivalves. The following characters were taken into account: shell length (L) in mm, shell height (H) in mm, height/length ratio (H/L), shell convexity (C) in mm, convexity/length (C/L) ratio, shell mass (SM) and body mass (BM) in g, sex, age, total mass of zebra mussels on the shell (ZMM) in g.

Environmental factors:

a. **Macrophytes.** The variable describes the presence of macrophytes at a sampling site, scale: 0 – absent, 1 – sparse, 2 – abundant;
b. **Distance from shore.** The variable describing the distance at which unionids were found, scale: <2 m and >2 m;
c. **Depth minimum.** The variable describes the smallest depth at which bivalves were present;
d. **Depth maximum.** The variable describes the greatest depth at which bivalves were present (except the Sulejowski Reservoir);
e. **Mineral fraction in the sediments.** The variable describes the content of inorganic compounds in the bottom sediments, in eight granulometric classes;
f. **Organic fraction in the sediments.** The variable describes the content of organic matter in the bottom sediments, in eight granulometric classes;
g. **Total seston.** The variable describes the content of dry seston mass in the water;
h. **Organic seston.** The variable describes the content of organic matter in the dry mass of total seston;
i. **Inorganic seston.** The variable describes the content of mineral substances in the dry mass of total seston.

Water quality indices: BOD_5, total suspension (Suspension), nitrite nitrogen (Nitrite N), total phosphorus (Phosphorus), chlorophyll a (Chlorophyll) and coli titre of faecal type (Coli titre). Since the statistical analysis included results of measurements of each of the six listed indices in five consecutive years (1993–1997), they constitute a total of 30 partial variables.

Tests were performed on both non-standardised data and data standardised according to the age of the bivalves. Standardisation of the measurements for particular age classes made it possible to exclude the effect of age on the metric characters of the bivalves, leaving only the variation resulting from other factors. When differences between consecutive age classes were statistically insignificant, the classes were pooled.

3.3.2. Statistical methods

Factor analysis (Principal Components Method) was used to reduce the number of variables; it was performed on standardised data. For bi-variate analysis, the following principal components were obtained from dependent variables (metric characters):

1. SHELL SIZE – variable associated with parameters describing the bivalve size: length (L), height (H), convexity (C), shell mass (SM) and body mass (BM);
2. SHELL SHAPE – variable associated with H/L and C/L ratios.

The principal components used in the regression analysis were obtained from independent variables, environmental factors (a–i):

FACTOR I pertains to large particles (PARTICLES L) of mineral deposits (size classes 0.5–4.0 mm) and all size classes of organic deposits.

FACTOR II is associated with the finest mineral particles (<0.063–0.125 mm).

FACTOR III is associated with the minimum and maximum depth at which bivalves occurred.

FACTOR IV pertains to medium-sized mineral particles (0.125–0.5 mm, PARTICLES M).

The principal components in the regression analysis obtained from the variables describing the bottom sediments corresponded to FACTORS I, II and IV. FACTOR III was not used in the analysis, since in multivariate analysis non-transformed factors gave better results. In both analyses the total content of organic compounds was used (ORGANIC).

Among 30 variables of the group of water quality indices long-term mean values were calculated: Suspension, Nitrite N, Phosphorus, BOD_5, Coli titre.

A coefficient of condition (CC) was calculated in order to determine the condition of the bivalves. In order to eliminate negative values, the distribution was displaced by 15 units on the scale:

CC = (BM'+15)×0.01/{(L'+15)×(H'+15)×(C'+15)}, where

BM' – standardised body mass, L' – standardised shell length, H' – standardised shell height, C' – standardised shell convexity.

The variation of metric shell characters of the unionids between the five types of water habitats of the Pilica (considering differences between sexes) was tested with bi-variate analysis (ANOVA II). Because of large differences between the size of the analysed samples, when calculating square sums I used calculations according to type IV. The analysis included metric characters of species for which sufficiently abundant data existed, i.e. *Unio pictorum, Anodonta anatina* and *A. cygnea* f. *cellensis*. The mean values of analysed characters (in five types of habitats) were compared with multiple range test. In cases in which – when analysed with Leven test – variance was statistically significantly different between the discussed habitat types, Dunnett T3 test was used for comparisons. When the variance was different, Tukey B test was applied.

In order to determine the degree of mutual interdependence between the variables, Pearson linear correlation analysis was used (SOKAL & ROHLF 1981). Correlation between the body mass and standardised metric shell characters was analysed. The characters showing the highest correlation with the body mass included shell length and height, for which the correlation coefficients were higher than +0.91. When sex was considered, the correlation coefficient with shell height was somewhat higher and amounted to +0.93; for this reason in square and linear regression shell height instead of length was used.

Square and linear regression methods (SOKAL & ROHLF 1981) were applied to evaluate the effect of zebra mussel colonies growing on unionid shells on the unionid condition. Tests were made on age-standardised data. In the regression analysis the body mass was adopted as dependent, and shell height as independent variable. The regression was curvilinear or rectilinear. When both regressions (the one for the unionids devoid of zebra mussels, and the one for unionids bearing zebra mussel colonies) were curvilinear (regression equation $y = a + b_1x + b_2x^2$), b_2 values were compared with Student t-test.

In order to explain the variation in condition and density of unionids in the five types of habitats, multiple regression was used (SOKAL & ROHLF 1981). In this method independent variables were environmental factors (a-i) and water quality indices.

The size and skewness of all the samples fulfilled the required inequality, making the approximations based on normal distributions justified, i.e. $n>25\ á_3^2$, where: n – sample size, $á_3$ – coefficient of asymmetry (BARNETT 1982). Meeting this assumption made it possible to apply parametric tests.

In all the tests decisions were made at the significance level of 0.05. Null hypotheses were tested with double-tailed tests. All the calculations and graphs were made with statistical packet SPSS 6.1 and STATISTICA PL 5.1.

The simplified analysis of spatial-qualitative structure of the unionids in the studied area was based on indices of frequency (constancy) and dominance (GÓRNY & GRÜMM 1981, ALEXANDROWICZ 1987).

Frequency (C) is the ratio of the number of localities where a given species occurred to the total number of localities.

Dominance (D) is the ratio of the number of specimens of a given species to the total number of specimens.

The values of these indices were divided in two classes according to which each species was classified as a member of a definite association (according to DOBROWOLSKI 1963, after STRZELEC 1993). Critical values for the dominance index were adjusted to the specificity of the occurrence of unionids.

The constancy categories were the following: C – constant species, present in at least 40% localities, c – accessory species with frequency not reaching 40% localities. The dominance categories were: D – dominant species, constituting at least 10%, d – subdominant species (recedent) constituting less than 10%.

Characteristics of spatial and qualitative structure of species was expressed as the following categories: CD – common and abundant, Cd – common and unabundant, cD – rare and abundant, cd – rare and unabundant.

Especially valuable information pertains to species occurring very rarely and in very low numbers in the studied area (subrecedent accidental species). For this reason such species were distinguished within "cd" category. Their percentage does not reach 1% and they occur in less than 10% studied localities. In tables of constancy and dominance they are marked with an asterisk.

In considerations on the frequency of occurrence sampling points within water bodies (e.g. oxbow Placówka, sites 28a, 28b, 28c) were treated as separate localities. Likewise, the transect sites in the Sulejowski Reservoir, termed collectively transects (e.g. transect III, locality 54) include a number of sampling points.

Indices of frequency and dominance of unionids in the Pilica, oxbows and the Sulejowski Reservoir were calculated based on the density of bivalves in 1 m^2. In the case of tributaries the basis for calculations was relative abundance.

When calculating constancy, I analysed the occurrence of bivalves in the Pilica starting with the place where they appeared for the first time (Pukarzew, loc. 13) to the river mouth. Sections of the Pilica, tributaries and oxbows where no unionids were found, as well as localities where only qualitative materials were collected, were excluded from the analysis. Hence the numbers of localities that served as a basis for calculations of constancy indices were: mid Pilica 15, lower Pilica 24, tributaries 21, oxbows 21 and Sulejowski Reservoir 39.

RESULTS

4.1. OCCURRENCE OF UNIONIDS IN THE STUDY AREA

The analysis of occurrence of unionids in the Pilica catchment area was based on materials collected in quantitative and qualitative samples, of a total of 5,705 individuals, including: *Unio crassus* – 54, *U. pictorum* – 2,504, *U. tumidus* – 1,801, *Anodonta cygnea* f. *cygnea* – 30, *A. cygnea* f. *cellensis* – 540, *A. anatina* – 740, *Pseudanodonta complanata* – 36.

The density and abundance of unionids in the Pilica catchment area are shown in Tables 5 and 6. The structure of constancy and dominance of the species are presented in Table 7 and Fig. 4. A comparison of the structure of constancy and dominance in quantitative and semi-quantitative samples is shown in Table 8.

4.1.1. Review of species

Six unionid species and one form were recorded from the Pilica, its tributaries and floodplain water bodies, as well as the Sulejowski Reservoir: *Unio crassus* Philipsson, 1788, *U. tumidus* Philipsson, 1788, *U. pictorum* (Linnaeus, 1758), *Anodonta cygnea* (Linnaeus, 1758), *A. cygnea* f. *cellensis* (Schröter, 1779), *A. anatina* (Linnaeus, 1758) and *Pseudanodonta complanata* (Rossmässler, 1835).

1. *Unio crassus* Philipsson, 1788. Localities: Pilica: 15, 18, 25, 26, 27, 30, 38a; tributaries: 16, 19, 20, 34, 35 (Fig. 5). A European species, in Poland found on lowlands and uplands. It inhabits clear running waters of sandy or sandy-gravelly bottom. In Poland, like in other European countries, its gradual extinction is observed, resulting from water pollution and eutrophication (PIECHOCKI & DYDUCH-FALNIOWSKA 1993, PIECHOCKI 1996). In the Pilica catchment area it is very rare and occurs in low numbers (Table 7). In quantitative samples it was found only at 4 localities where (converted to 1 m^2) I found a total of 5.1 specimens which is only 0.3% samples. This places *U. crassus* in the category of very rare species of very low abundance (cd*) (Table 7, Fig. 4).

In the study area the species was recorded from the mid section of the Pilica, between Maluszyn (loc. 15) and Kurnędz (loc. 38) where (including semi-quantitative samples) it was found in a total of seven sites (Table 8). Its mean density ±SE was 0.46 ±0.21 Nm^{-2} (Table 5). It was also present in the tributaries of the mid Pilica: Zwlecza (loc. 16), Czarna Włoszczowska (locs 19, 20) and Czarna Konecka (locs 34, 35). There its relative abundance was higher (2.81 ± 1.16 Nt^{-1}) than in the Pilica (0.51±0.24 Nt^{-1}) (Table 6).

2. *Unio tumidus* Philipsson, 1788. Localities: Pilica: 14, 15, 18, 25, 26, 27, 29, 30, 31, 31a, 38a, 38b, 40, 41, 58, 95; tributaries: 19, 32, 85, 86, 89; oxbows: 28a, 39a, b, 4a, b, e, 101b; Sulejowski Reservoir: 48, 50, 51a, 51b, 52, 53a, 53b, 54, 55, 56a, b (Fig. 6).

A European species, in Poland distributed in the lowlands and in the upland belt (PIECHOCKI & DYDUCH-FALNIOWSKA 1993). In the Pilica catchment area it is common (43.4% localities) and abundant (48.0% specimens) which places it in CD category; it was found in all the types of habitats (Table 7, Fig. 4).

In the Pilica *U. tumidus* occurs almost exclusively in the mid section of the river where it was found in 16 sites; it is decidedly more abundant than the remaining species. Its mean density from the place where it appears (ca. 23 km below Koniecpol in Mosty; loc. 14) to Sulejów (at a total of 11 localities in the shore zone of the river bed where it was present in quantitative samples) was 67.07±25.5 Nm^{-2}. Below the reservoir, in the whole lower section of the river, I found only two individuals, one below the dam in Smardzewice (loc. 58), the other – below Nowe Miasto (loc. 95). Besides the Drzewiczka, *U. tumidus* was infrequent in clear and natural tributaries to the mid Pilica (Czarna Włoszczowska, Czarna Konecka). Its mean relative abundance ±SE (converted to 15 min) was 4.3±2.69 Nt^{-1}, the maximum being 15 Nt^{-1} – in the mouth section of the Czarna Włoszczowska (loc. 19) (Table 6). *U. tumidus* was also found, though not abundant, in oxbows of the mid section of the Pilica permanently connected with the river (Placówka loc. 18, Taraska loc. 39, Podklasztorze loc. 42). Its mean density there was 1.64 ±1.14 Nm^{-2} (Table 6). Except a single specimen found in Zagroby (loc. 101b) I did not observe it in oxbows in the lower section of the Pilica. *U. tumidus* is common in the Sulejowski Reservoir (64.1% localities) but is distinctly less abundant than *U. pictorum.* Its proportion in the total number of specimens from the reservoir was 13.3% (Table 7).

3. *Unio pictorum* (Linnaeus, 1758). Localities: Pilica: 13, 14, 15, 18, 25, 26, 27, 29, 30, 31a, b, 38a, 40, 41, 58, 72, 77, 79, 82, 83, 95, 96, 97a, b, 98, 99, 100, 102, 103; tributaries: 19, 32, 35, 85, 86, 89; floodplain

Table 5. Comparison of density (a) and relative abundance (b) of Unionidae in Pilica River

Species	middle and lower river section		middle river section		lower river section		N (min.–max.)		number of localities	
	a	b	a	b	a	b	a	b	a	b
1. *Unio crassus*	0.21±0.10	0.25±0.12	0.46±0.21	0.51±0.24	0	0	0–2	0-3	4	7
2. *Unio tumidus*	30.74±13.35	22.11±10.1	67.07±25.5	45.9±19.19	0	0.07±0.07	0.4–252	1–252	11	16
3. *Unio pictorum*	10.58±3.49	11.68±3.39	18.68±6.55	17.61±6.34	4.03±2.26	6.03±2.42	0.05–64	1–76	22	29
4. *Anodonta cygnea* f. *cellensis*	1.33±1.17	2.15±2.10	2.9±2.53	4.48±4.37	0	0	4–28	1.3–57	2	2
5. *Anodonta cygnea* f. *cygnea*	0.37±0.37	0.85±0.85	0	0	0.75±0.75	1.76±1.76	–9	–23	1	1
6. *Anodonta anatina*	3.29±1.03	6.44±2.16	4.51±1.71	3.75±1.56	2.44±1.31	9.08±3.98	0.04–17	0–51	16	24
7. *Pseudanodonta complanata*	0.56±0.27	0.92±0.58	1.23±0.53	1.85±1.12	0	0	0.3–6	0–15	7	8

a – $(N \cdot m^{-2})$±SE
b – $(N \cdot t^{-1})$±SE
$(N \cdot m^{-2})$ – Number of specimens collected in 1 m^2 area
$(N \cdot t^{-1})$ – Number of specimens collected in semi-quantitative samples
SE – standard error

Table 6. Comparison of density and relative abundance of Unionidae in the tributaries and floodplain water bodies (oxbows) of the Pilica River

Species	oxbows			Sulejowski Reservoir				tributaries		
	$(N \cdot m^{-2})$±SE	Nmax	L	Transect	$(N \cdot m^{-2})$±SE	Nmax	L	$(N \cdot t^{-1})$±SE	Nmax	L
1. *Unio crassus*	0				0		0	2.81±1.16	5.7	5
2. *Unio tumidus*	1.64±1.14	24	7	III	1.14±0.51	5	12	4.3±2.69	15	5
				II	2.66±0.97	12	12			
				I	2.78±0.87	8	12			
3. *Unio pictorum*	2.71±1.70	36	12	II	7.69±2.15	28	13	8.0±3.27	22	6
				I	14.28±7.70	50.6	7			
4. *Anodonta cygnea* f. *cellensis*	5.26±1.02	16	20	III	–	–	–	0		
				II	1.94±0.76	6.6	13			
				I	3.61±1.87	13.3	2			
5. *Anodonta anatina*	0.04±0.03	0.6	2	III	2.25±1.64	20	12	2.65±1.13	10	8
				II	0.61±0.35	4	13			
				I	1.90±1.29	9.3	7			
6. *Pseudanodonta complanata*	0.07±0.05	1	2		0		0	0.87±0.37	1.25	2

N, Nmax – mean and maximum number of specimens
L – number of localities
$(N \cdot m^{-2})$ – Number of specimens collected in 1 m^2 area
$(N \cdot t^{-1})$ – Number of specimens collected in semi-quantitative samples

Table 7. Constancy of occurrence (C) and dominance (D) structure of Unionidae in the study area (data recalculated to 1 m^2)

	number of localities	%	number of specimens in 1 m^2	%	categories
Middle and lower section of the Pilica River combined					
U. pictorum	22	56.4	262.82	22.71	CD
A. anatina	16	41.03	78.99	6.83	Cd
U. tumidus	11	28.21	755.80	65.31	cD
P. complanata	7	17.95	13.55	1.17	cd
U. crassus	4	10.26	5.1	0.44	cd*
A. c. f. *cellensis*	2	5.13	32	2.77	cd
A. c. f. *cygnea*	1	2.56	9	0.78	cd*
total	**39**		**1157.26**		
Middle section of the Pilica River					
U. pictorum	11	73.33	202.85	19.15	CD
U. tumidus	11	73.33	755.8	71.37	CD
A. anatina	8	53.33	49.7	4.69	Cd
P. complanata	7	46.67	13.55	1.3	Cd
U. crassus	4	26.67	5.1	0.48	cd
A. c. f. *cellensis*	2	13.33	32	3.02	cd
total	**15**		**1059**		
Lower section of the Pilica River					
U. pictorum	11	45.83	59.97	61.03	CD
A. anatina	8	33.33	29.29	29.81	cD
A. c. f. *cygnea*	1	4.17	9.00	9.16	cd
total	**24**		**98.26**		
Oxbows					
A. c. f. *cellensis*	20	95.2	110.65	54.0	CD
U. pictorum	12	57.1	57.05	27.9	CD
U. tumidus	7	33.3	34.6	16.9	cD
A. anatina	2	9.5	0.9	0.4	cd*
P. complanata	2	9.5	1.6	0.8	cd*
total	**21**		**204.8**		
Sulejowski Reservoir					
U. pictorum	30	79.5	329.4	74.8	CD
U. tumidus	23	64.1	73.2	16.6	CD
A. anatina	16	41.0	28.1	6.4	Cd
A. c. f. *cellensis*	9	20.5	9.5	2.2	cd
total	**39**		**440.2**		
Tributaries (based on semi-quantitative samples)					
A. anatina	8	38.1	21.2	20.2	cD
U. pictorum	6	28.6	48.0	45.6	cD
U. tumidus	5	23.8	21.5	20.4	cD
U. crassus	535	23.8	13.2	12.5	cD
P. complanata	1	9.5	1.3	1.2	cd*
total	**21**		**105.2**		

CD – common and abundant species
Cd – common and unabundant species
cD – rare and abundant species
cd – rare and unabundant species
* – very rare and unabundant species

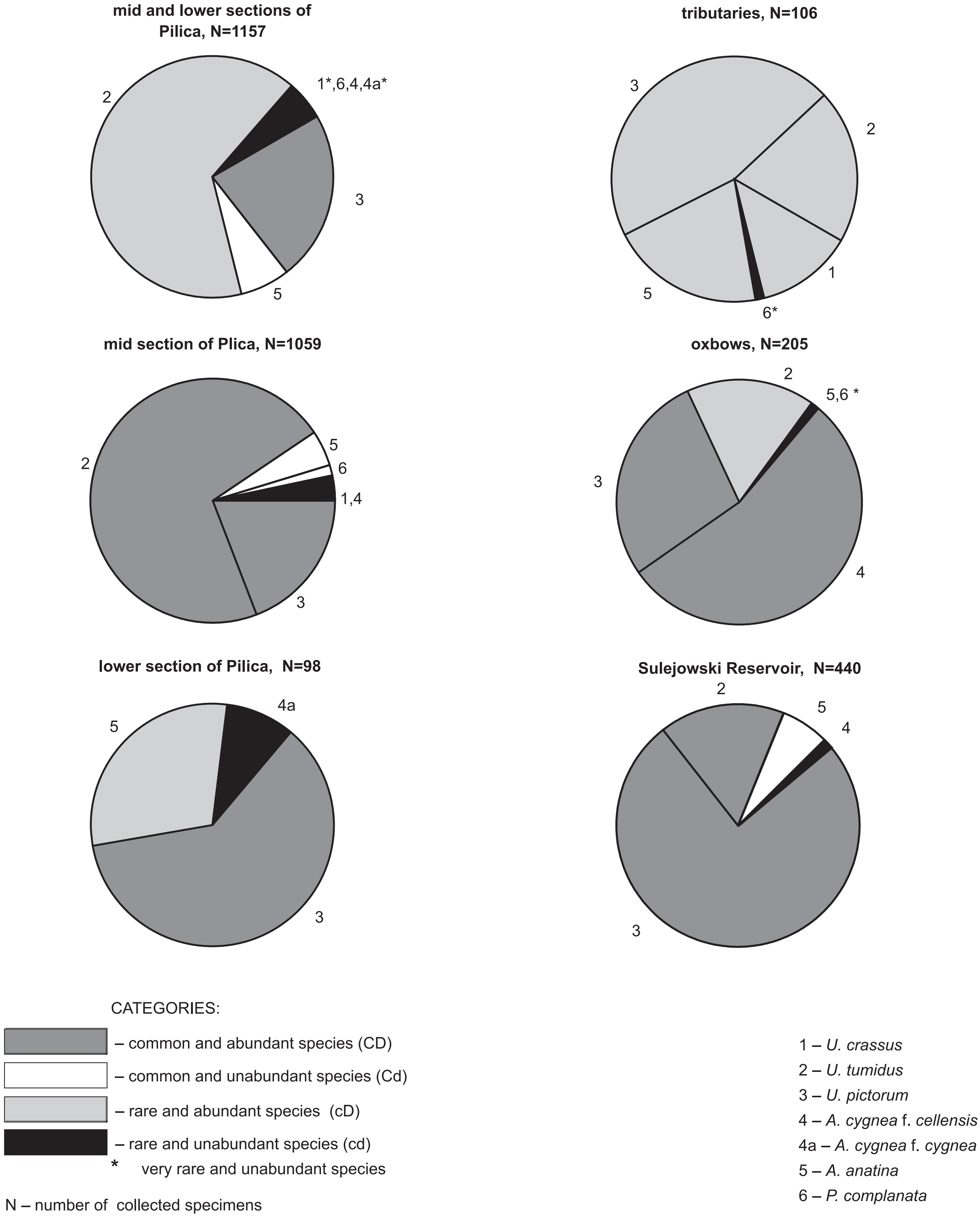

Fig. 4. Dominance structure of unionids in various kinds of habitats (based on samples from 1 m^2, for tributaries on semi-quantitative samples)

water bodies: 28a, 39a, b, 42a, b, c, d, e, 49a, f, 66, 101b; Sulejowski Reservoir: 48, 50, 51a, b, 52, 53a, b, 54, 55, 56a, b (Fig. 7).

A European species. In Poland common in lowlands and uplands (PIECHOCKI & DYDUCH-FALNIOWSKA 1993). It is the most common unionid species in the study area; it shows a high frequency (65.7% localities) and abundance. The proportion of *U. pictorum* in quantitative samples of unionids constitutes 36.1% collection which places it in the category of common and abundant species (CD) (Table 7, Fig. 4).

In the Pilica it is a common species (56.4% localities). It appears at the 82nd km of the river course (locality 13, Pukarzew) – as the first unionid species – and is present till the mouth. It was recorded from 29 localities. The mean density calculated for 22 localities (quantitative samples) in the whole course of the Pilica is 10.58±3.49 Nm^{-2}; it is clearly higher in the mid section (18.68 ±6.55 Nm^{-2}) (Table 5) where *U. pictorum* forms dense beds the largest of which (64 Nm^{-2}) was noted near Kurnędz (loc. 38). Below the Sulejowski Reservoir it is less abundant and till the river mouth occurs as scattered. The mean density at localities situated in the lower section of the Pilica was 4.03±2.59 Nm^{-2}. In the tributaries it is less frequent (28.6% localities) (Table 7). It occurs there mainly in mouth sections: Czarna Włoszczowska (loc. 19), Czarna Konecka (locs 32, 35) and Drzewiczka (locs 85, 86, 89) where it is the most abundant (90% collection in the tributaries) species. It is the second most frequent (57% localities) after *A. cygnea* in oxbows. Its mean density there amounted to 2.71±1.70 Nm^{-2} (Table 6), sometimes reaching much higher values (36 Nm^{-2}, loc. 42). It is the dominant species in the Sulejowski Reservoir where it constituted nearly 80% unionids (Table 7).

4. *Anodonta cygnea* (Linnaeus, 1758). Localities: Pilica: 29, 38b, 102; floodplain water bodies: 28a, b, c, 39a, b, c, 42a, b, c, d, e, 49a, b, c, d, e, f, 66, 101a, c; Sulejowski Reservoir: 51a, 52, 54 (Fig. 8).

A Palaearctic species. It lives in ponds, oxbows, canals and slow-flowing rivers. It prefers not very soft,

Table 8. Comparison of constancy and dominance structure of Unionidae in the Pilica River in quantitative samples recalculated to 1 m^2 (a) or in semi-quantitative samples recalculated to 15 min. sampling (b)

	a		b		a		b	
	number of localities	%	number of localities	%	number of specimens	%	number of specimens	%
middle and lower river sections combined								
Unio pictorum	22	56.4	29	74.4	262.82	22.7	367.2	28.5
Anodonta anatina	16	41.0	24	61.5	78.99	6.8	177.65	13.8
Unio tumidus	11	28.2	16	41.0	755.8	65.3	638	50.0
Pseudanodonta complanata	7	17.9	8	20.5	13.55	1.2	10.5	0.8
Unio crassus	4	10.3	7	17.9	5.1	0.4	8.25	0.6
Anodonta cygnea f. *cellensis*	2	5.1	2	14.3	32	2.8	58.3	4.5
Anodonta cygnea f. *cygnea*	1	2.6	1	7.1	9	0.8	23	1.8
total	**39**		**32**		**1157.26**		**1282.9**	
middle river section								
Unio pictorum	11	73.3	14	93.3	202.85	19.2	231.7	23.1
Unio tumidus	11	73.3	14	93.3	755.8	71.4	637.7	63.7
Anodonta anatina	8	53.3	11	73.3	49.7	4.7	54.8	5.5
Pseudanodonta complanata	7	46.7	8	53.3	13.55	1.3	10.5	1.0
Unio crassus	4	26.7	7	46.7	5.1	0.5	8.25	0.8
Anodonta cygnea f. *cellensis*	2	13.3	2	13.3	32	3.0	58.3	5.8
total	**15**		**15**		**1059**		**1001.25**	
lower river section								
Unio pictorum	11	45.8	15	55.6	60.0	61.0	135.5	48.1
Anodonta anatina	8	33.3	13	48.1	29.3	29.8	122.8	43.6
Anodonta cygnea f. *cygnea*	1	4.2	1	3.7	9.0	9.2	23.0	8.2
Unio tumidus	0		2	7.4	0.0	0.0	0.4	0.1
total	**24**		**17**		**98.26**		**281.7**	

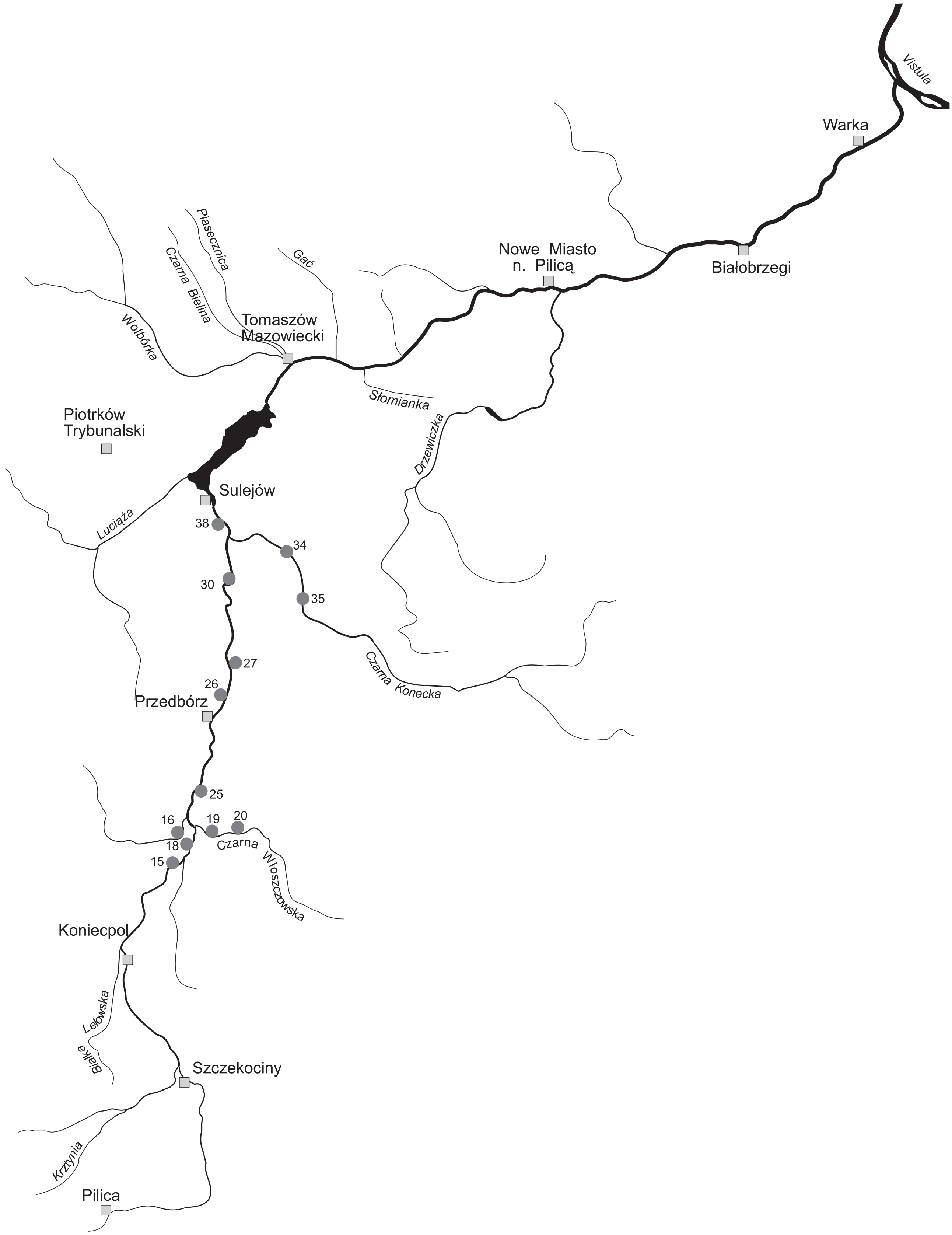

Fig. 5. Distribution of *Unio crassus* in the Pilica catchment area

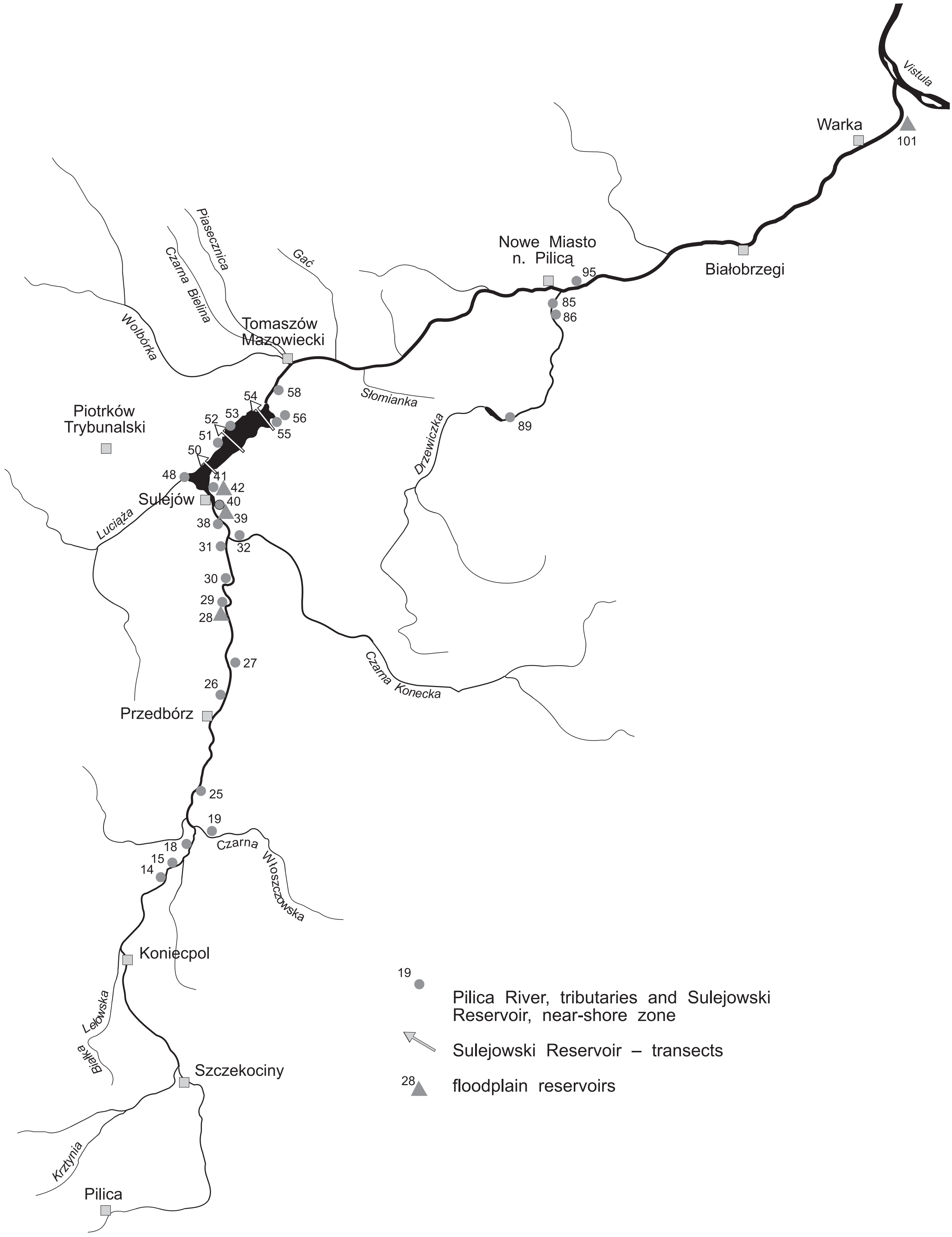

Fig. 6. Distribution of *Unio tumidus* in the Pilica catchment area

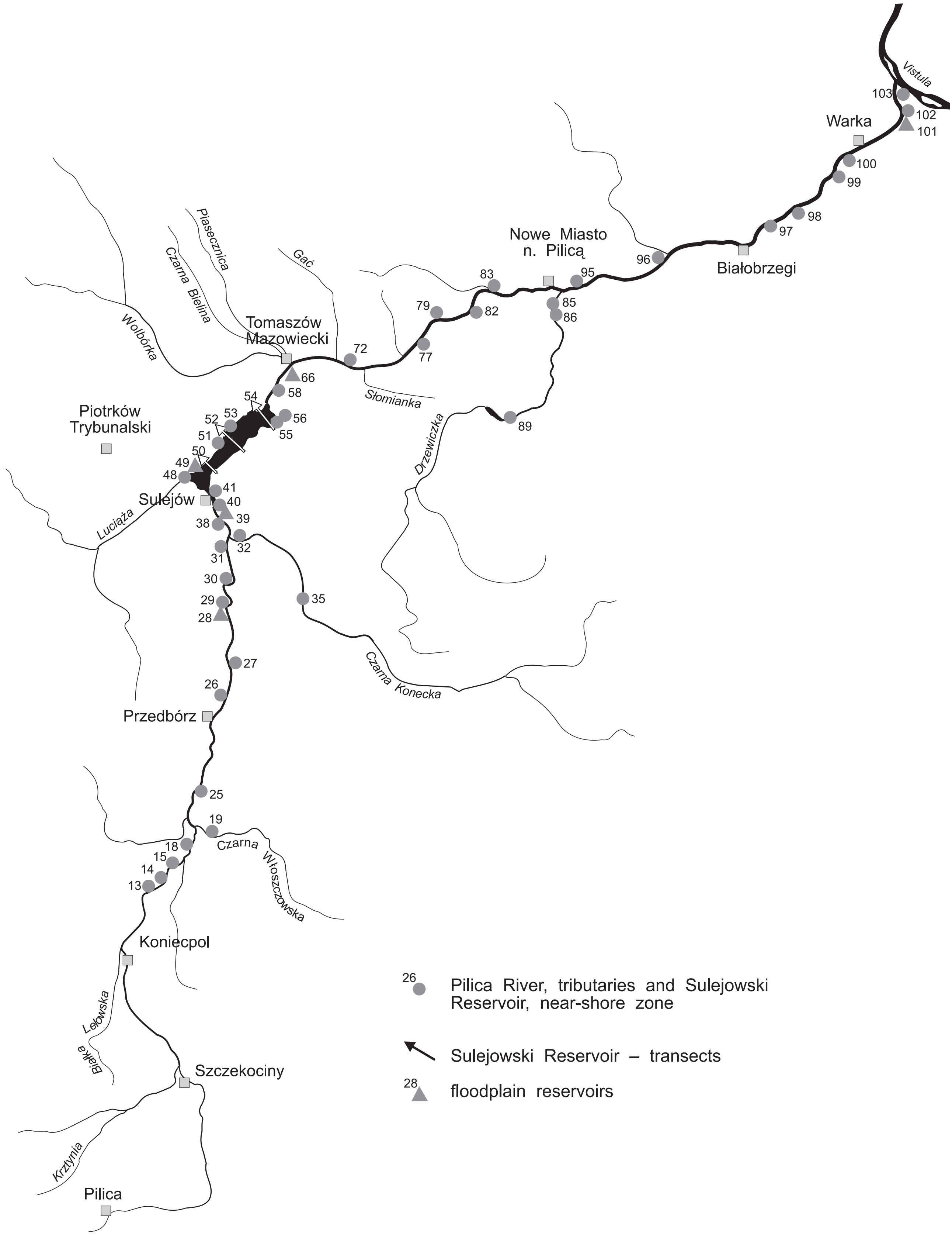

Fig. 7. Distribution of *Unio pictorum* in the Pilica catchment area

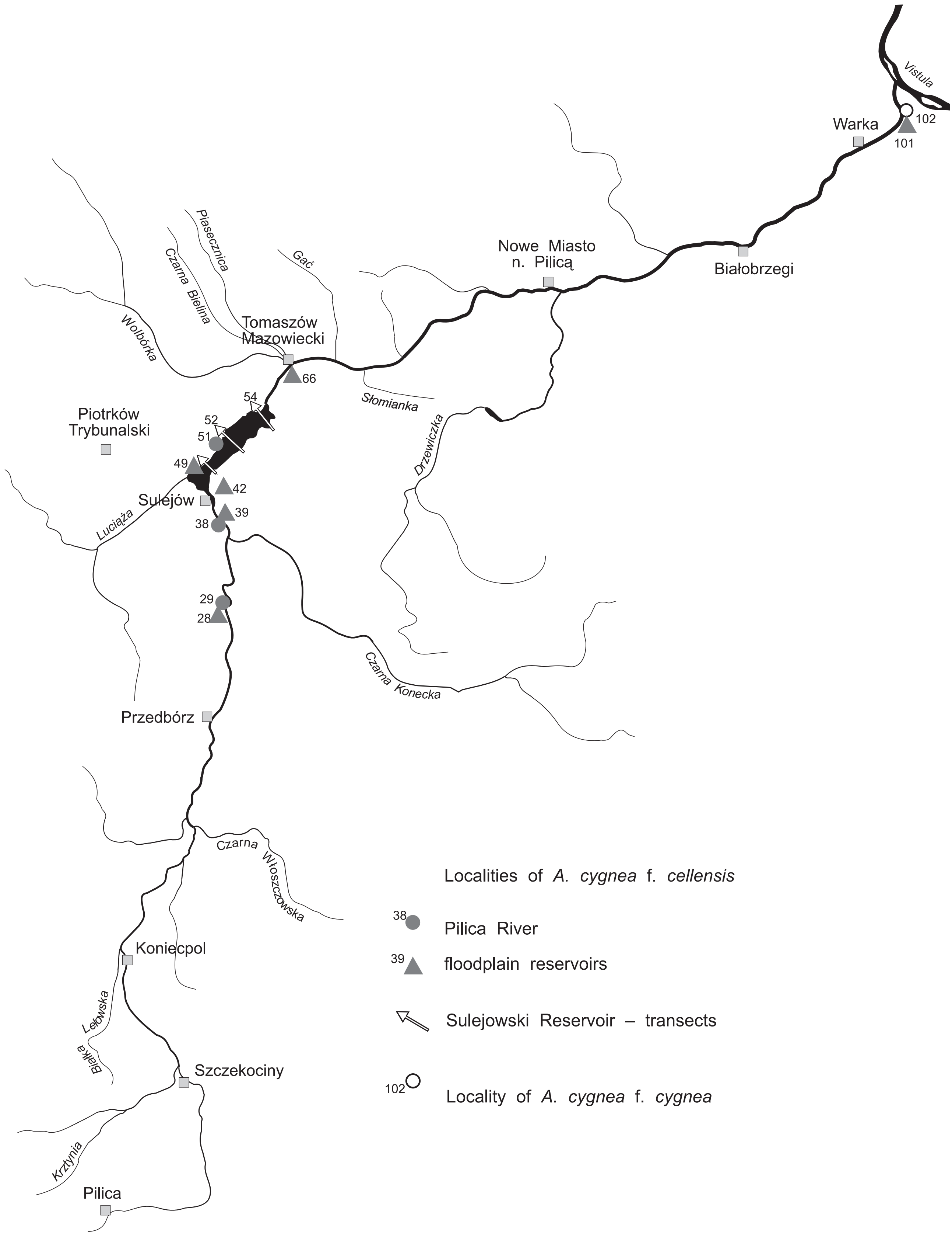

Fig. 8. Distribution of *Anodonta cygnea* f. *cellensis* and *A. cygnea* f. *cygnea* in the Pilica catchment area

muddy bottom (PIECHOCKI & DYDUCH-FALNIOWSKA 1993).

In the Pilica catchment area it is rare and not abundant (category cd) (Table 7, Fig. 4). It was recorded from 31 localities (31.3%). There were 157.2 specimens in quantitative samples (converted to 1 m^2).

Two ecological forms are distinguished within *A. cygnea*: *A. cygnea* f. *cygnea* (Linnaeus) and *A. cygnea* f. *celensis* (Schröter) (GITTENBERGER et al. 1998). The forms were formerly regarded as distinct species or subspecies (GEYER 1927, ZHADIN 1938, URBAŃSKI 1957). However, no clear differences were found in their geographical distribution (GITTENBERGER et al. 1998). WALLBRINK's (1992) studies showed that within their distribution range they did not form mixed populations, but were two forms of different shell morphometry. According to JANSSEN & DE VOGEL (1965) the wide variation of *A. cygnea* results from ecological factors rather than genetic background. The forms differ in the following characters:

A. cygnea f. *cygnea*: shell oval, tumid, length 160–200 mm, height 90–120 mm, convexity 50–60 mm (ZHADIN 1938). The largest known shell described by FELIKSIAK (1930) was 21.5 cm long. The height/length ratio (H/L) is higher than in *A. cygnea* f. *cellensis* and ranges from 0.50 to 0.60. The lower margin of the shell is more or less arcuately bent. The growth lines are clearly visible. It occurs mainly in stagnant waters but is reported also from large rivers though it avoids swift current. Within the distribution range it is known from few localities (FELIKSIAK 1930, GITTENBERGER et al. 1998).

A. cygnea f. *cellensis*: shell tongue-like elongate, length 96–160 mm, height 42–70 mm, convexity 30–50 mm (ZHADIN 1938). The lower margin of the shell is almost straight in its mid part. The height/length ratio (H/L) ranges from 0.47 to 0.50. It occurs in oxbows, lakes and ponds and is much more common than f. *cygnea*.

In the study area both forms of *A. cygnea* were found, but f. *cellensis* was clearly more common; it was recorded from 24 localities. *A. cygnea* f. *cygnea* was found only in the mouth section of the Pilica (loc. 102).

A. cygnea occurred mainly in oxbows where it was the most common and abundant species (CD category) (Table 7). The mean density calculated for 20 sampling sites in 6 floodplain water bodies was 5.26±1.02 Nm^{-2} (Table 6). Numerous empty shells of *A. cygnea* were observed on an uncovered bottom of a pond on the stream Gać in Konewka (loc. 70) (within half an hour 90 shells were collected from an area of ca. 1,200 m^2). Several live specimens of yellowish coloured shells (the largest 177 mm in length) were found in discharge canals of the karst vaucluse Niebieskie Źródła (leg. T. JANISZEWSKI). The species had not been recorded from that site earlier (PIECHOCKI 1972a). In the Sulejowski Reservoir, *A. cygnea* was found rarely and was not abundant (category cd). Its mean density there ranged from 1.94 to 3.61 Nm^{-2} depending on the location of the site (Table 6). It was also found in two sites in the mid Pilica.

The other ecological form – *A. cygnea* f. *cygnea* – was very rare and unabundant in the study area (cd* category) (Table 7). It was found only in the mouth section of the Pilica which constitutes only 1% unionid localities.

5. *Anodonta anatina* (Linnaeus, 1758). Localities: 14, 15, 18, 26, 27, 29, 30, 31a, b, 38a, 40, 58, 72, 73, 77, 79, 83, 84, 95, 96, 97b, 99, 100, 103; tributaries: 19, 20, 21, 32, 85, 86, 88, 89; floodplain water bodies: 28b, 101b; Sulejowski Reservoir: 48, 50, 51a, b, 52, 53a, 54, 55 (Fig. 9).

A Palaearctic species. In Poland it is found in stagnant and slow-flowing waters, on a sandy or sandy-muddy bottom (PIECHOCKI & DYDUCH-FALNIOWSKA 1993). In the analysis of constancy and dominance structure (Table 7), based on quantitative samples, the species in the catchment area is rare and not abundant (cd).

Starting with the 86th km of the river it occurs along its whole course. Most frequently (53.3% localities) it was found in the mid section of the river where it was classified as common but not abundant (Cd). In the lower section it was found only at 33.3% localities (Table 7). Its abundance is much lower than that of the common *U. pictorum* and *U. tumidus*, and the mean density in the whole river is 3.29±1.03 Nm^{-2} (Table 5). In the tributaries it was among the most frequent species and occurred, though not in great numbers, in their mouth sections (Table 6). Also in the Sulejowski Reservoir it was common but not abundant (Cd) (Table 7).

6. *Pseudanodonta complanata* (Rossmässler, 1835). Localities: Pilica: 15, 18, 26, 27, 29, 30, 31a, 38a; tributaries: 19, 32; floodplain water bodies: 28a, b (Fig. 10).

A West-European species. In Poland it is found mainly in shallow, pure rivers of sandy or sandy--gravelly bottom (PIECHOCKI & DYDUCH-FALNIOWSKA 1993). In lowlands found also in lakes of sandy or muddy littoral (URBAŃSKI 1957, BERGER 1960, DYDUCH & FALNIOWSKI 1979).

In the Pilica catchment area the species is very rare and unabundant (cd* category), found at 9 localities (9.1%) where it was always represented by single individuals. In quantitative samples (converted to 1 m^2) a total of 14.3 specimens were found which makes 0.7% unionid collection in the study area (Table 7).

The occurrence of *P. complanata* was limited to a 60-km section of the mid Pilica, between Maluszyn and Kurnędz. It occurred in all kinds of habitats but its numbers were very low. Its mean density was 1.23±0.53 Nm^{-2} (Table 5), the highest density (6 Nm^{-2}) was observed in Dęba (loc. 26). Single individuals were found also in lothic, mouth sections of the Czarna Włoszczowska (Ciemiętniki, loc. 19) and

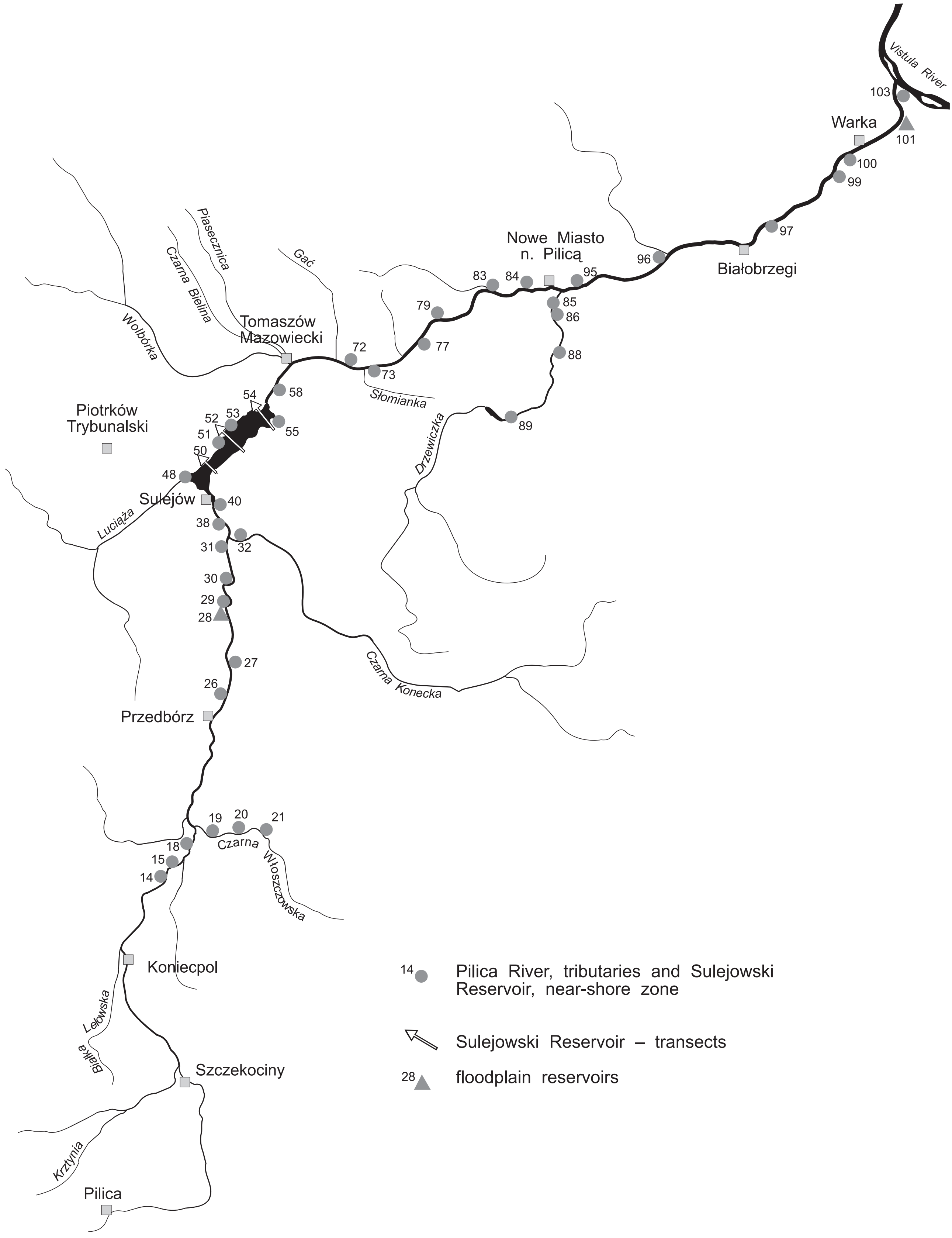

Fig. 9. Distribution of *Anodonta anatina* in the Pilica catchment area

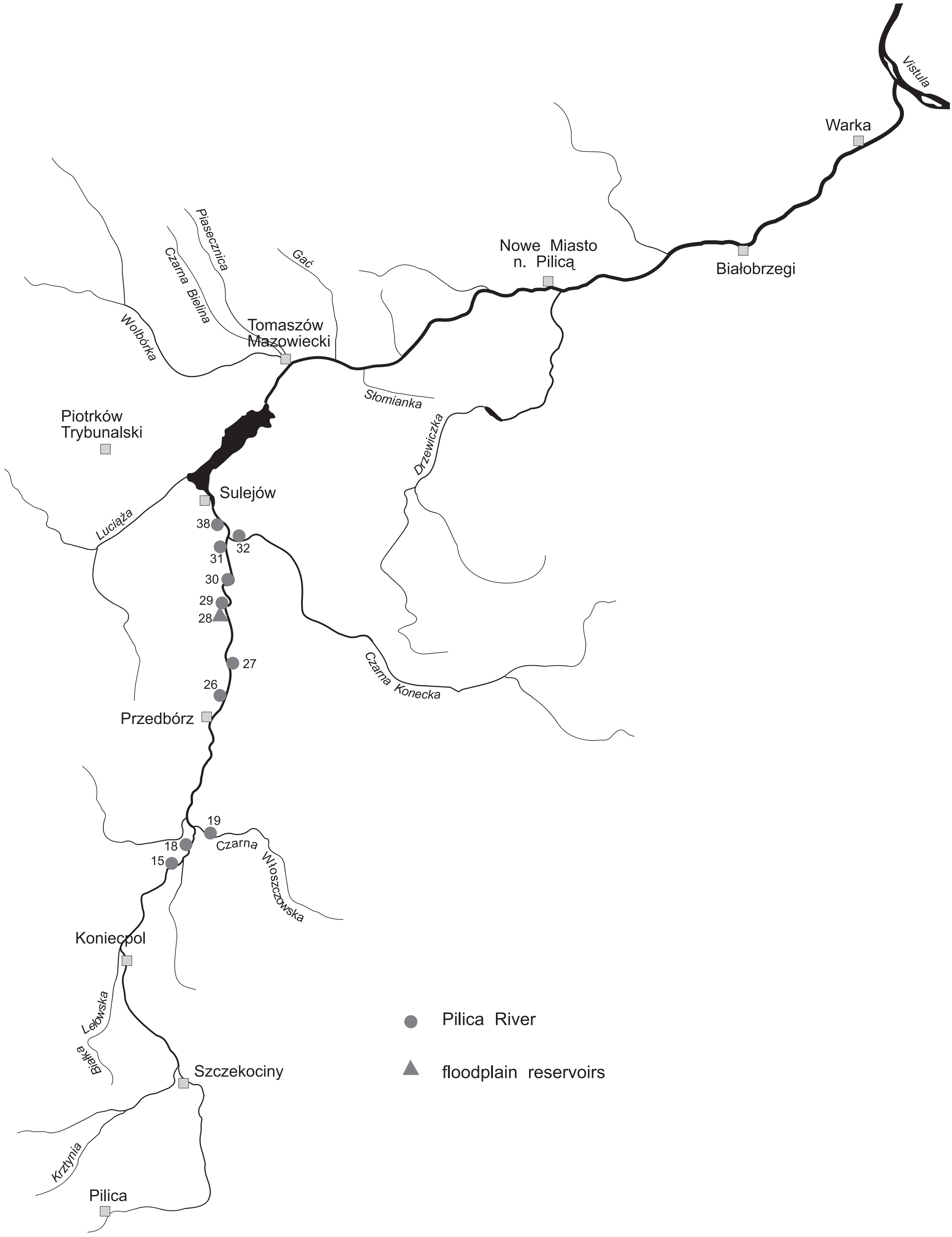

Fig. 10. Distribution of *Pseudanodonta complanata* in the Pilica catchment area

Czarna Konecka (Taraska, loc. 32) (Table 6). Two specimens were found in an oxbow of the Pilica in Placówka (loc. 28).

4.1.2. Dominance structure in unionid populations

The constancy and dominance structure of unionids in the study area are presented in Table 7. Its graphical counterpart is Figure 4. A comparison of the constancy and dominance structure in samples from an area of 1 m^2 and in semi-quantitative samples is shown in Table 8.

River

Among the 46 localities studied (49 sampling sites) located along the whole course of the river, unionids were found in 32 (65.2% localities) in semi-quantitative samples (Table 8). The number of localities where unionids were found in quantitative samples was much lower and amounted to only 25 (Fig. 11). A total of 1,158 unionid specimens representing all the native species were collected in quantitative samples from the Pilica (Table 7).

No unionids were found in the upper section of the river. The unionid locality which is the closest to the sources is situated in the mid section of the river, at the 82nd km (Pukarzew, loc. 13). The occurrence of particular species along the river course is presented in Figs 12, 13.

Mid section (1)

Within an 85-km section of the river – from Pukarzew to the backwater zone of the Sulejowski Reservoir below Sulejów – the distribution of the bivalves was continuous (100% localities) and they were abundant (Fig. 11). In quantitative samples converted to the area of 1 m^2, a total of 1,059 specimens (1,001.2 specimens in semi-quantitative samples) representing all the native species were collected (Table 8). Common and abundant species (CD category) included *U. tumidus* and *U. pictorum.* An absolute dominant, however, was *U. tumidus,* constituting 71.4% unionid collection from the mid Pilica. Common, though clearly less abundant (Cd category) were *A. anatina* (4.7% unionids) and *P. complanata* (1.3% unionids), rare in Poland. *U. crassus*, getting increasingly rare in the Polish waters, was also found though it was rare and not abundant (cd category, 0.5% total collection) (Table 7). The diversity of habitats in the mid section of the Pilica proved to be favourable also for *A. cygnea* f. *cellensis* whose aggregation of high density (28 Nm^{-2}) was found in Kurnędz (loc. 38b). The density was 141.95 Nm^{-2} (Table 5).

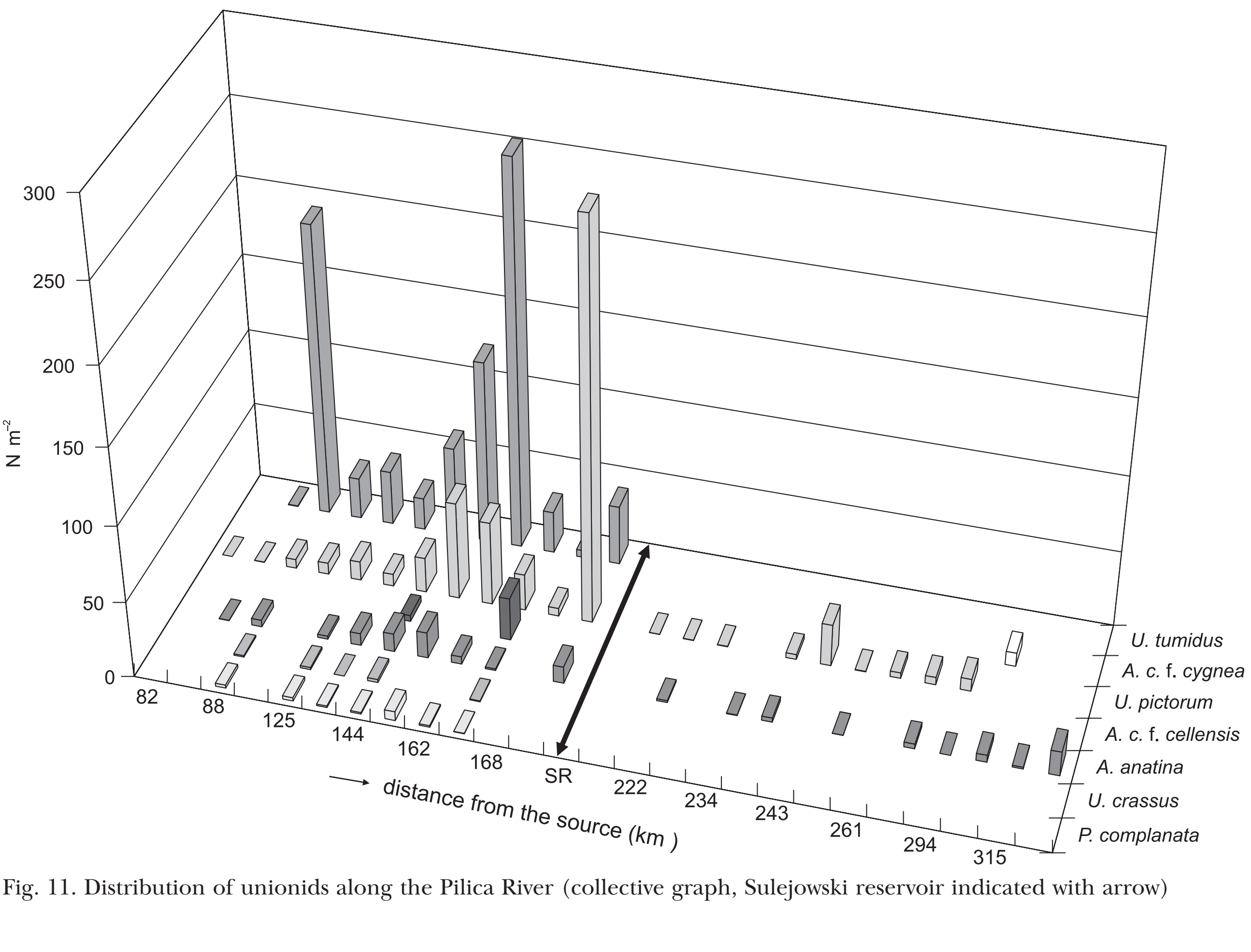

Fig. 11. Distribution of unionids along the Pilica River (collective graph, Sulejowski reservoir indicated with arrow)

Lower section (2)

Below the Sulejowski Reservoir, in the whole lower section, there is a distinct qualitative and quantitative impoverishment of the unionid fauna. The fauna is dominated (90%) by two species which are common and abundant in that section: *U. pictorum* and *A. anatina*.

In the first 80 km below the reservoir the abundance of unionids was low, the bivalves occurring singly and scattered (locs 58, 77, 83) (Fig. 11). In a 15-km, polluted section from Tomaszów to Teofilów no bivalves were found in quantitative samples.

Only as far as from the 277th km of the river (loc. 96, Osuchów) to the mouth of the Pilica unionids were more numerous and formed two-species aggregations which, however, did not reach a size comparable to unionid beds in the mid Pilica (Fig. 11).

In semi-quantitative samples (converted to 15 min) in the lower section of the river, only 281.7 individuals (8.3 in samples from the area of 1 m^2) were collected (Table 8) – four times less than analogous values from the mid Pilica.

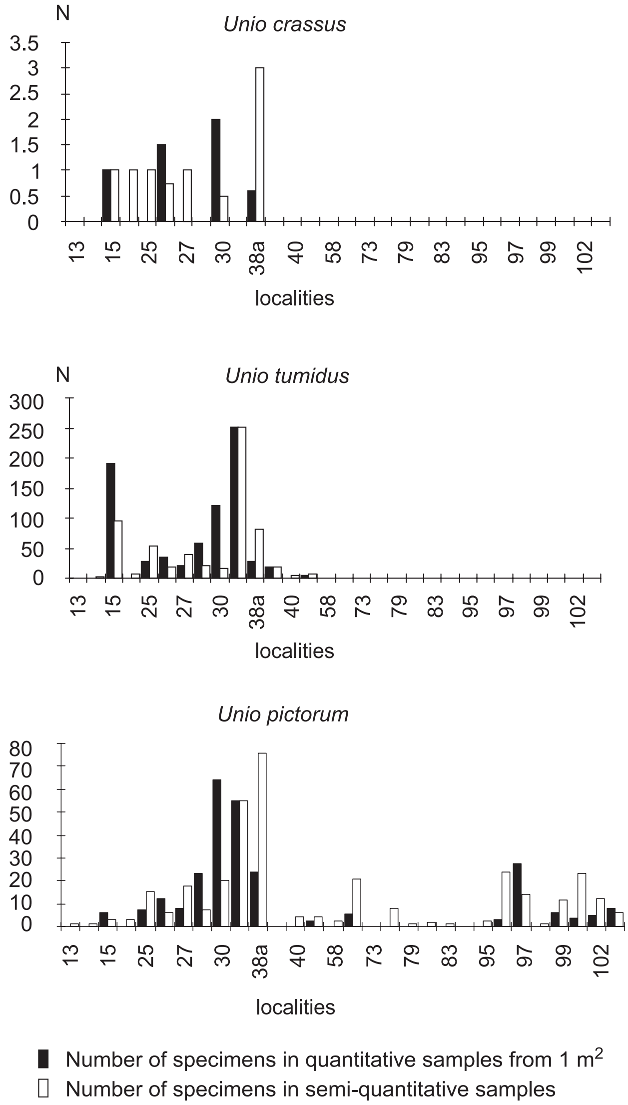

Fig. 12. Occurrence of *Unio crassus*, *U. tumidus* and *U. pictorum* along the Pilica River

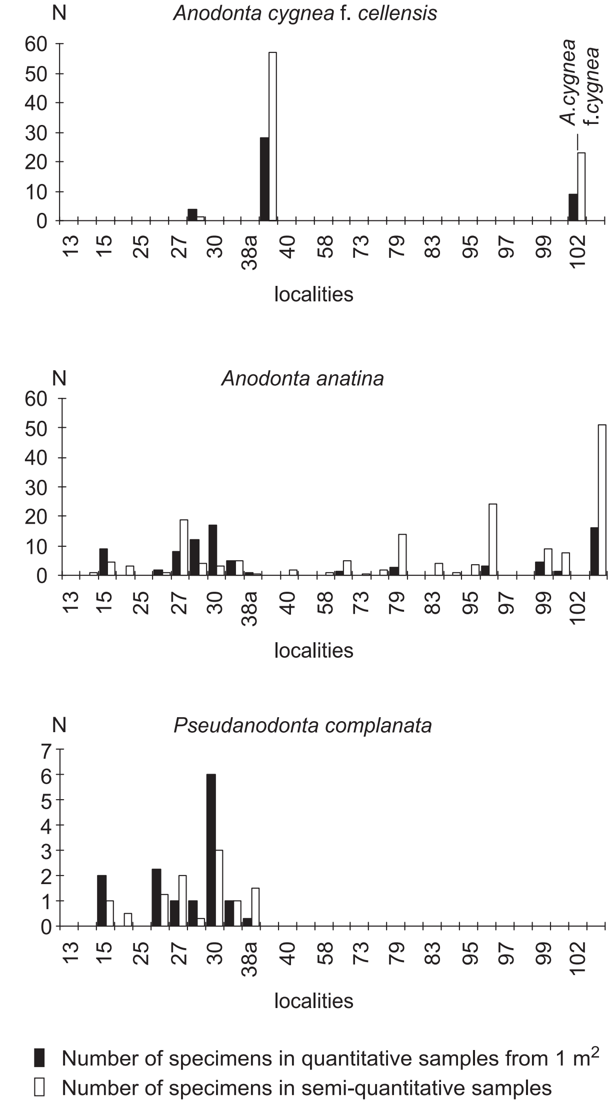

Fig. 13. Occurrence of *Anodonta cyganea*, *A. anatina* and *Pseudanodonta complanata* along the Pilica River

In 76% localities *U. pictorum* and *A. anatina* co-occurred in various proportions. Besides them I found *A. cygnea* f. *cygnea* (9.2% total collection) (Table 7) in the mouth section of the Pilica (loc. 102), as well as two specimens of *U. tumidus*.

Tributaries (3)

Among the 12 studied tributaries unionids were found in four: Zwlecza, Czarna Włoszczowska, Czarna Konecka and Drzewiczka (Fig. 14).

Except *A. cygnea*, all the native species were found there. It is noteworthy that unionids in the tributaries were much less abundant and more scattered compared to the Pilica, which accounted for the negative results of most quantitative samples. Rough data, reflecting only tendencies in the qualitative and spatial distribution of unionids in the studied tributaries, are based on semi-quantitative samples. Four species: *A. anatina, U. pictorum, U. tumidus* and *U. crassus* were

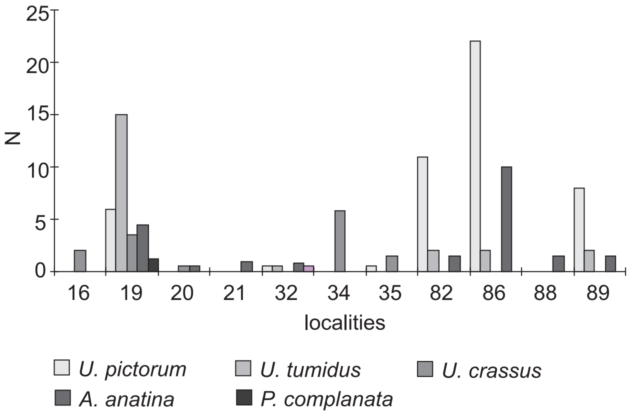

Fig. 14. Occurrence of unionids in the tributaries (based on semi-quantitative samples). Localities: 16 – Zwlecza, 19–21 – Czarna Włoszczowska, 32–35 – Czarna Konecka, 82–89 Drzewiczka

rare but fairly abundant, which placed them in cD category (Table 7, Fig. 4). The most frequent species in the tributaries was *A. anatina* (32% localities). The most abundant was *U. pictorum*, constituting 45.6% unionids. A comparison of the results of collection of *U. crassus* obtained from semi-quantitative samples in the mid Pilica (where at 7 localities it reached a density of 8.25 Nt^{-2}) and in the tributaries (where at 5 localities 13.2 Nt^{-1} were found) (Tables 5, 6) suggests that in the tributaries *U. crassus* found better conditions. However, *P. complanata* was found there only sporadically (category cd*).

In semi-quantitative samples (converted to 15 min) 105.8 individuals were found. Their species composition and abundance varied between the tributaries. In the tributaries of the mid Pilica five unionid species were found. The species richness and abundance of the bivalves were the highest in the Czarna Włoszczowska, especially in its mouth section, where *U. tumidus* (46% total collection), *U. pictorum, U. crassus* and *A. anatina* were found, as well as single specimens of *P. complanata*.

In the Czarna Konecka the most abundant species was *U. crassus*, constituting over 70% unionids.

In the Drzewiczka, a tributary of the lower section of the Pilica, the most frequent though not numerous was *A. anatina* (72% localities). The most abundant species was *U. pictorum* (41 specimens constituting 66% collection). Species sensitive to water pollution – *U. crassus* and *P. complanata* – were not found in that river. Finding single individuals of *U. tumidus* in a few sites in the lower section of the Drzewiczka is noteworthy. Its presence in the mouth section of the river may be associated with the occurrence of *U. tumidus* in the Pilica, from where the bivalve could be transported by glochidia-infected fishes.

Oxbows (4)

The studies in 10 oxbows along the mid and lower sections of the river (a total of 31 sampling sites) revealed the presence of unionids in six of them: Placówka (loc. 28), Podklasztorze (loc. 42), Barkowice (loc. 49), Taraska (loc. 39), Tomaszów--Brzustówka (loc. 66) and Zagroby (loc. 101) (Fig.

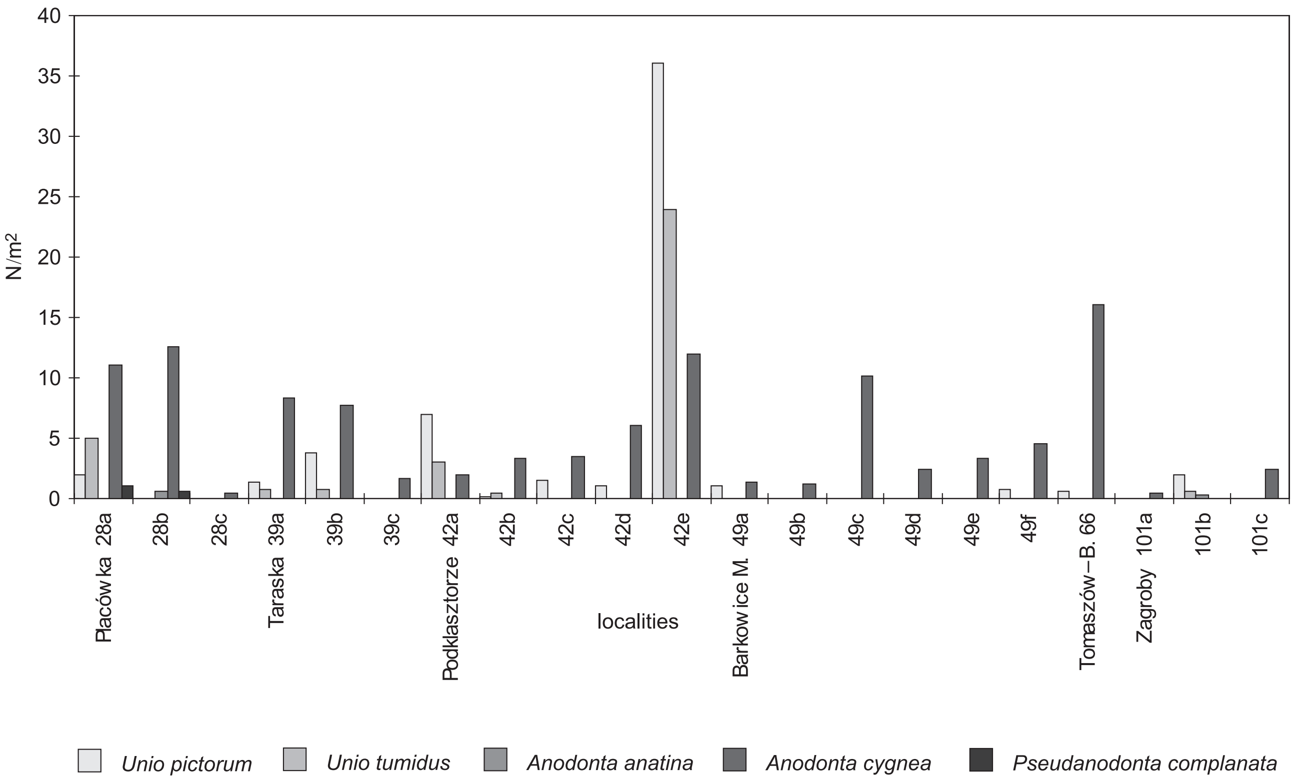

Fig. 15. Occurrence of unionids in the oxbows

15). In quantitative samples, 204.8 specimens were found. The dominant species was *A. cygnea* f. *cellensis,* present in all the oxbows (95.2% localities), and also the most abundant (54% collection in oxbows) (Table 7). *U. pictorum* was a common and abundant species (CD category). I found it in 57.1% localities, and its proportion was 27.9% collection. A fairly abundant but less frequent than the preceding one was *U. tumidus,* ranked in cD category. *A. anatina* and *P. complanata* occurred in the oxbows sporadically (category cd*). I found no live bivalves in isolated oxbows, remote from the river, much vegetated and very muddy (locs 80b and 37), or in a very marshy reservoir in Gapinin (loc. 81).

Sulejowski Reservoir (5)

In the littoral of the Sulejowski Reservoir and along the three transects, a total of 2,291 specimens of unionids representing four species were collected.

In quantitative samples, converted to 1 m^2, a total of 723.4 specimens were found. The dominant was *U. pictorum* (79.5% localities, 69.9% total collection) (Table 7). *U. tumidus* was also common and abundant, being present at 64.1% localities. Besides *U. pictorum,* it was classified in CD category (Fig. 4) but was much less numerous (13.3% total collection) (Table 7). The third common, but unabundant species (9.7% collection thus placing it in Cd category) was *A. anatina. A. cygnea* was rare and scarce in the reservoir; it was present at 20.5% localities and classified in cd category.

The analysis of data from the transects showed that unionids occurred within the whole reservoir, except *A. cygnea* which was present only in its mid and upper parts (Figs 16, 17).

The densest aggregations of unionids were noted in the mid and upper parts of the Sulejowski Reservoir. A similar distribution was shown by *U. tumidus. A. anatina* – present in the whole reservoir – was slightly more abundant in its lower part. In the mid and upper parts of the reservoir, in muddy bottom deposits,

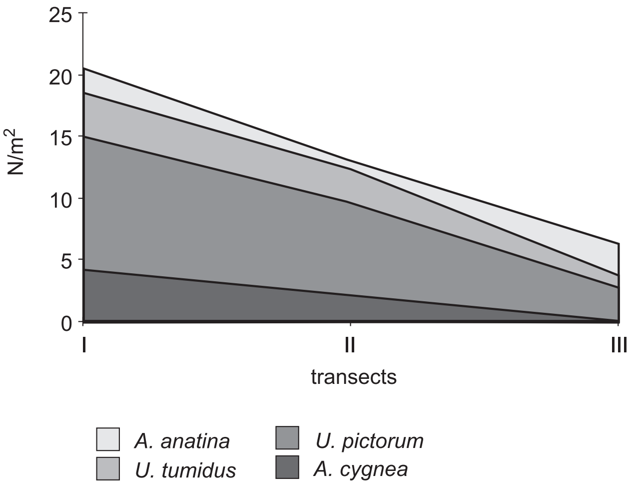

Fig. 16. Distribution of unionids along the Sulejowski Reservoir

A. cygnea appeared (Table 6). Its large aggregation was found in a branch of the reservoir in the backwater zone (loc. 49, Fig. 20).

The densities were the lowest in localities situated in the lower part of the reservoir. In the region of the dam examining the bottom at depths of 3–15 m showed a complete absence of unionids. On the eastern shore (locs 55, 56) the mean density was 2.5–3.9 Nm^{-2}, farther, at the line of transect III (Swolszowice-Tresta) it was 6.2 Nm^{-2}. The bivalve density was higher in the mid part of the reservoir and amounted on an average to 12.9 Nm^{-2} (transect II, loc. 52), and in the shore zone it even exceeded 20 Nm^{-2} (loc. 53a, b). Density maxima were observed in the backwater zone. In transect I (loc. 50) the mean density was 20.5 Nm^{-2}, reaching the highest value of 61.4 Nm^{-2} in the region of Barkowice. In the river section of backwater of the reservoir (loc. 48, Murowaniec) I found the highest density of bivalves in the catchment area – 310 Nm^{-2}.

4.1.3. Structure of spatial distribution in various habitats

River

Unionids grouped in the belt of bottom close to the shore, several metres wide, in a zone of calm water outside the current or where the current speed was moderate (Fig. 18). Only sporadically they were observed in strong current in the mid part of the river bed. More often they were found near sandy islands, in sheltered places (loc. 97b). Where the shores of the Pilica were low, unionids were found already about a dozen centimetres from the shore (loc. 27) in shallow or very shallow water. At shores covered by reeds they usually occurred outside the vegetation belt but close to it (loc. 15). *U. tumidus, U. pictorum* and *P. complanata* reached their maximum densities in calm water 1–2 m from the shore, though single specimens were found also in moderate current, where the distance from the shore usually exceeded 4 m. *A. anatina* occurred in the calm shore zone as well as in places of moderate flow. *U. crassus* was fairly often found in the current, some distance from the shore, but could also be found in stagnant shore waters.

At high banks the bivalves inhabited depressions or "shelves" washed out below the turf layer. On steep, undercut slopes – because of a too strong current – the distribution of bivalves was usually limited to a narrow strip near the shore, 0.5–1.0 m wide (locs 26, 48).

River populations of unionids were characterised by a clustered distribution in the bottom sediments. In the mid Pilica the bivalves formed multi-species aggregations in the near-shore zone. They were either "bed" aggregations, extending along the river bed for several dozen or even over 100 m (locs 15, 31, 38), or "point" aggregations, limited by the extent of the

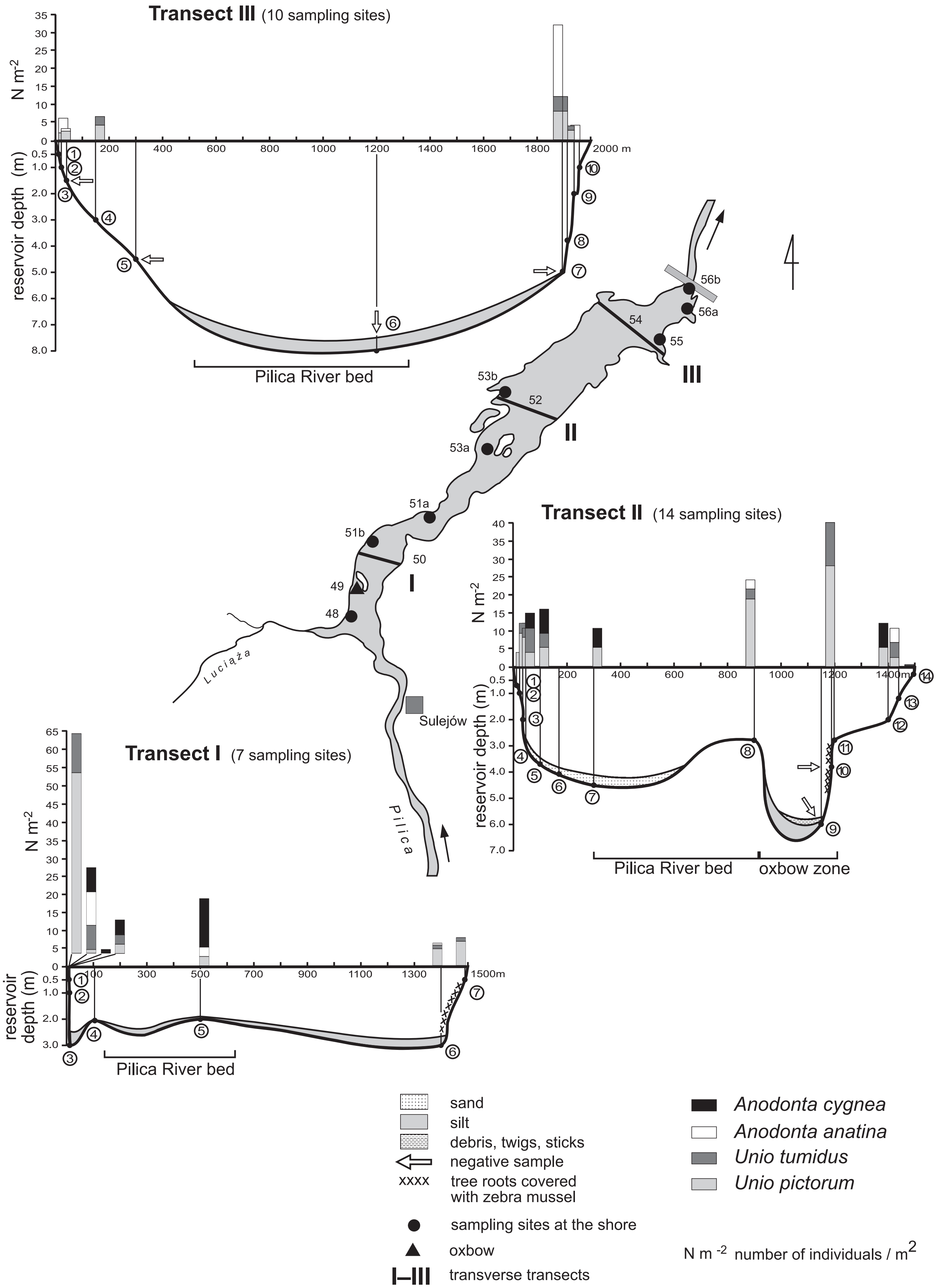

Fig. 17. Occurrence of unionids in the Sulejowski reservoir (transverse transects)

microhabitat (a small bay, a depression, a fragment of muddy bottom behind a vegetation clump) to a small space of a few metres or less (locs 25, 26, 27, 29, 30). The density in the beds varied from 54 Nm^{-2} in Błota (loc. 25) to 82 Nm^{-2} in Kurnędz (loc. 38a), 95 Nm^{-2} in Maluszyn, to the highest in Komorniki Bielskie – 252 Nm^{-2}. The most common species in both types of aggregations was always *U. tumidus* (60–81% collected bivalves). The proportion of other species was much lower, especially *U. crassus* and *P. complanata* which usually occurred singly. In lothic sections (loc. 40) and below sources of water pollution (locs 13 and 14) the bivalves were few and much scattered.

In much smaller water courses, such as tributaries of the Pilica, unionids occurred singly or in small aggregations in the near-shore zone. They were rather frequent also in the current, where, however, no bed-like aggregations were observed.

Oxbows

The bivalve distribution varied depending on the water body size, shape and the degree of connection with the Pilica. In small oxbows permanently connected with the river, e.g. Podklasztorze (loc. 42) (Fig. 19), a considerable proportion of euryoecious species (*U. pictorum* and *U. tumidus*) was observed, which were the most numerous in the zone of contact oxbow-river (sampling sites a, e). Deep within the oxbow (sampling sites b, c, d) the situation changed in favour of the stagnophilous *A. cygnea*. A different distribution of unionids was observed in a narrow flow canal, a branch of the Sulejowski Reservoir in Barkowice (Fig. 20). *A. cygnea* occurred in the entire canal, reaching its maximum density in its mid part (10.2 Nm^{-2}). Single individuals of *U. pictorum* appeared only in the zone of connection with the Sulejowski Reservoir. A different picture of unionid

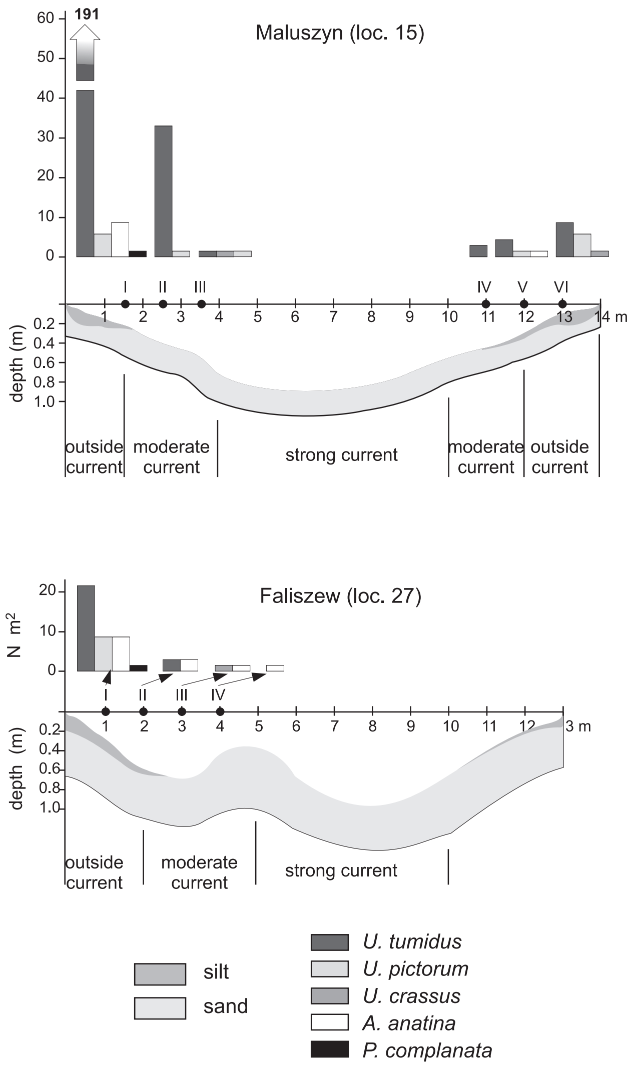

Fig. 18. Distribution of unionids in the transverse profile of the river

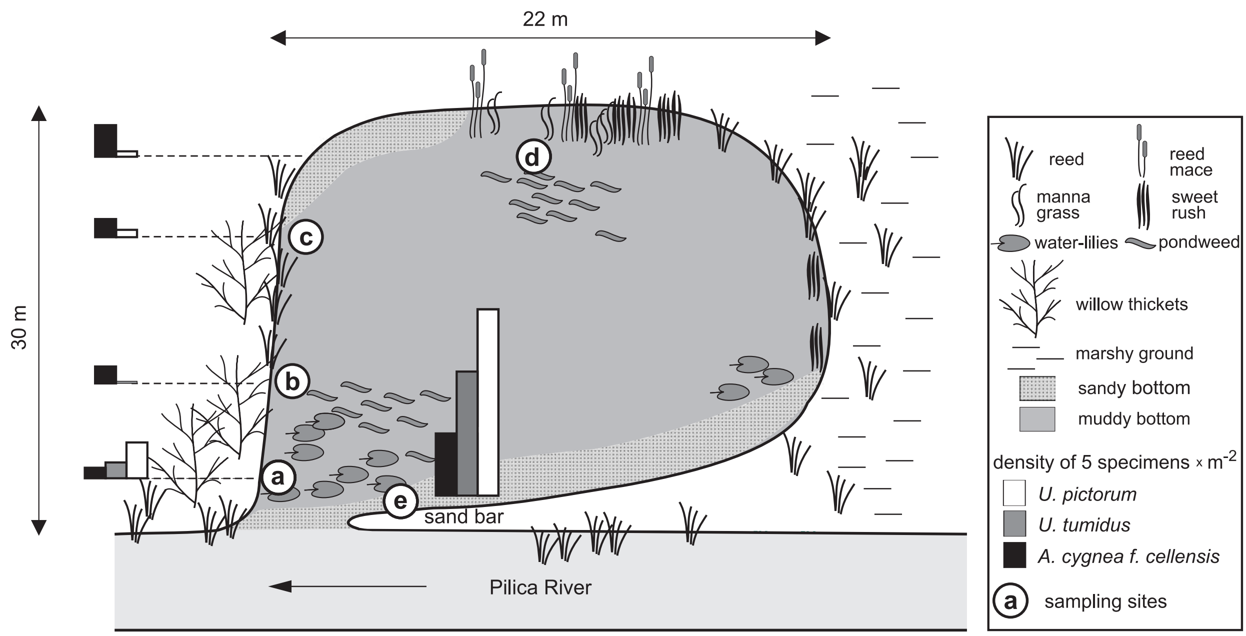

Fig. 19. Distribution of unionids in the oxbow Podklasztorze (loc. 42)

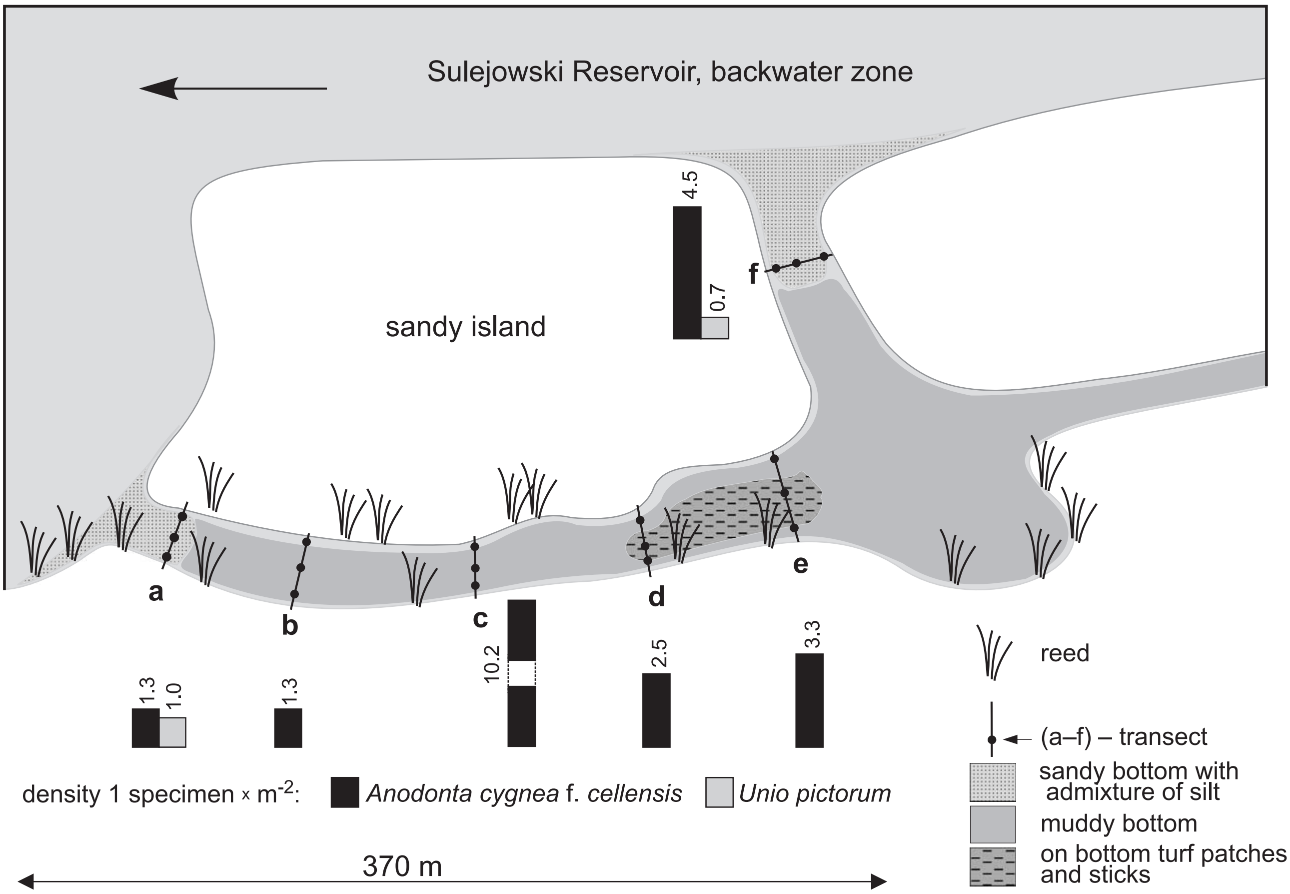

Fig. 20. Distribution of unionids in the oxbow Barkowice Mokre (loc. 49)

distribution was found in a long (2 km) branch of the river in Zagroby (loc. 101). Stagnant sections of an oxbow character were inhabited almost exclusively by *A. cygnea*, while the meandering, fast-flowing section was characterised by the presence of *U. pictorum, U. tumidus* and *A. anatina*. The maximum density of *A. cygnea* in the study area (16 Nm^{-2}) was noted in the shore zone of the oxbow Tomaszów-Brzustówka (loc. 66). In most of the examined water bodies – especially where on the central part of the bottom there was a thick layer of silt – the bivalves were more numerous in the shore zone, in both shallow (up to 0.5 m) and deep (ca. 1 m) places.

Sulejowski Reservoir

The analysis of the materials collected along the transverse transects (Fig. 17) revealed that the occurrence of the unionids in the reservoir was limited to the littoral zone. The bivalves preferred the near-shore bottom belt, where the mean density amounted to 14.9 Nm^{-2}, and the maximum was 61.4 Nm^{-2}. This was also confirmed by samples taken in the shore zone of the reservoir. In the shallows at the western shore, especially in the localities of the mid and upper sections, between Adamowo and Barkowice, large aggregations of unionids were noted (20–29 Nm^{-2}). In September 1997, when as a result of intense water discharge the level of the reservoir was by 90 cm lower than the maximum water table elevation (166.0 m) (information obtained from Mr. B. RZERZYCHA, M. Sc., Department of Water Production, Sulejów), accumulating of large numbers of live bivalves in shallow parts of the reservoir was observed. In the near-shore

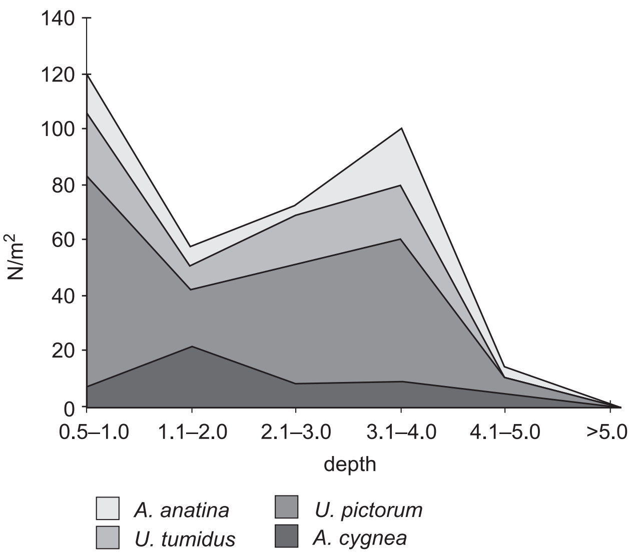

Fig. 21. Vertical distribution of unionids in the Sulejowski Reservoir

belt of the bottom (depth 0.1–0.5 m), 1,054 unionid individuals were collected from an area of 50 m^2.

Materials collected along the transects show also a vertical differentiation of unionid distribution (Fig. 21). Unionids were numerous to the depth of 4 m. Their highest densities (39.8 Nm^{-2}) were noted in the near-shore zone, at depths of 0.5–1.0 m. Slightly lower densities were found up to 4 m depth. A clear decrease in the bivalve abundance was observed below 4 m; the density there amounted to 4.9 Nm^{-2}. The bivalves preferred a sandy bottom or sand with an admixture of silt. In deeper layers (5–8 m), in the belt of accumulation of loose silty sediments, no live bivalves were found.

4.2. EFFECT OF ENVIRONMENTAL FACTORS ON UNIONIDS

4.2.1. Bottom sediments, vegetation, distance from shore and configuration

Unionid samples collected in a variety of habitats along the Pilica, and also in selected tributaries, floodplain reservoirs and the Sulejowski Reservoir made it possible to reconstruct habitat preferences of particular species. They are presented in Figure 22. Results of calculations of multiple regression explaining effects of environmental factor on density and life condition of unionids are presented in Table 9.

Two species – *U. pictorum* and *A. anatina* – occurred in all kinds of river habitats, *U. pictorum* being generally common and abundant, while *A. anatina* was clearly less frequent and usually occurred in low numbers. The distribution pattern of these two species in the study area qualifies them as euryoecious species.

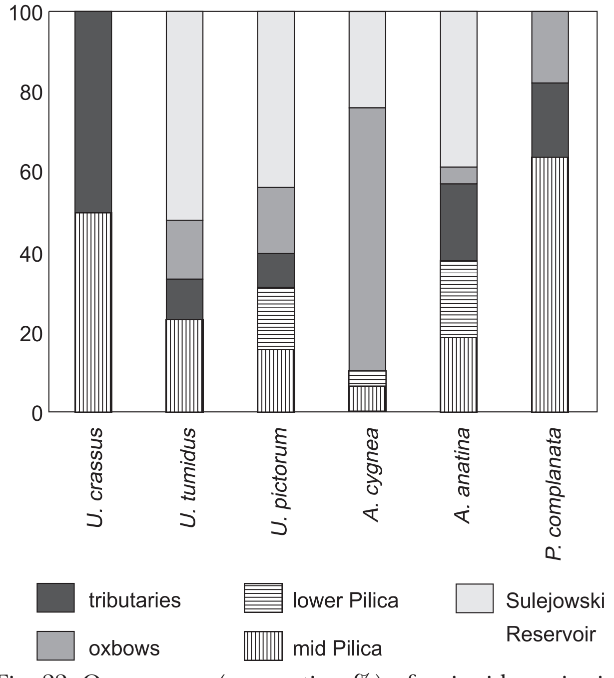

Fig. 22. Occurrence (proportion %) of unionid species in five types of habitats

U. pictorum inhabited a sandy and sandy-muddy bottom, of moderate grain size (0.125–0.5 mm, FACTOR IV), sometimes also a muddy bottom, though fine-grained, organic-rich silt (FACTOR II) affected negatively its density. A reverse dependence was found for the condition of these bivalves, since coarse-grained (0.5–4.0 mm), organic-rich bottom deposits (FACTOR I) affected it positively.

U. pictorum lives in river bays, on sloping bottom near the banks of the Pilica, in the main current, and also around sandy islands, but was most often found close to the shore (negative correlation with distance from shore). It prefers rather shallow sections of the river (negative correlation with factors describing minimum and maximum depth) and avoids clumps of macrophytes (Table 9).

U. pictorum was relatively common in the oxbows, especially their parts connected to the Pilica. It was a dominant species in the Sulejowski Reservoir, where it was found mainly on sandy bottom with a thin layer of silt. It was common and abundant in shallow, shore parts of the reservoir, and especially abundant in the backwater zone (260 Nm^{-2}). It was present in the tributaries, though much less frequent than in the Pilica (28.6% localities).

A. anatina, a species common but not abundant in the study area, was often found in the river (41.0% localities) and the Sulejowski Reservoir (41.0% localities). It was somewhat less frequent in the tributaries (38.1% localities). In the oxbows it was sporadically found close to their connection with the river. Like *U. pictorum*, the species preferred a sandy bottom, though usually with an admixture of silt. Its density was positively affected by medium-grained sediments (0.125–0.5 mm, FACTOR IV). It avoided very muddy places, abounding in organic matter (FACTOR II, ORGANIC). The presence of organic matter in the sediments positively affected the condition of *A. anatina*, while coarse-grained deposits had a limiting effect (Table 9). In the river it was found in the shore zone, where in shallow places it reached its highest density (maximum and minimum depth). There it usually grouped in the belt of aquatic vegetation and on its margin. Single individuals were found in places of moderate water current.

The group of euryoecious forms includes also *U. tumidus*, a common and abundant species, which was absent only from the lower section of the Pilica. With *U. pictorum*, it was a co-dominant in the mid Pilica where it was recorded from 73.3% localities. It occurred in rather shallow layers of silt and sandy-muddy or sandy sediments. It reached its highest density in fine-grained deposits, of the grain size 0.063–0.125 mm (FACTOR II), with an admixture of medium-grained components (FACTOR IV) and organic-rich (ORGANIC) (Table 9). At the same time,

Table 9. Results of calculations of multiple regression explaining effects of environmental factors on density and condition of Unionidae

Environmental factor	b	β	t°	p	Environmental factor	b	β	t°	p
Unio pictorum									
Density (R^2 = 0.44043)					Condition (R^2 = 0.05126)				
Macrophytes	–5.510	–0.292	–8.759	0.0000	Depth min.	–0.177	–0.115	–2.742	0.0063
Distance from bank	–11.083	–0.079	–2.471	0.0138	Factor I	0.044	0.147	3.549	0.0004
Depth min.	–8.447	–0.090	–2.124	0.0341	Factor II	–0.038	–0.144	–3.531	0.0004
Depth max.	–19.126	–0.305	–7.094	0.0000	Factor IV	–0.035	–0.098	–2.410	0.0162
Organic	–0.718	–0.241	–7.032	0.0000					
Factor II	–2.400	–0.164	–4.869	0.0000					
Factor IV	8.566	0.430	12.576	0.0000					
Unio tumidus									
Density (R^2 = 0.68036)					Condition (R^2 = 0.26817)				
Macrophytes	16.141	0.160	4.843	0.0000	Macrophytes	0.074	0.255	4.892	0.0000
Depth max.	–51.743	–0.152	–3.516	0.0005	Depth min.	0.491	0.174	2.946	0.0034
Organic	3.491	0.193	5.675	0.0000	Depth max.	–0.338	–0.296	–5.290	0.0000
Factor II	83.838	0.738	14.206	0.0000	Organic	–0.009	–0.166	–3.427	0.0007
Factor IV	12.781	0.113	2.810	0.0052	Factor II	–0.091	–0.297	–5.005	0.0000
					Factor IV	–0.094	–0.271	–5.440	0.0000
Anodonta anatina									
Density (R^2 = 0.31054)					Condition (R^2 = 0.29926)				
Macrophytes	2.068	0.330	5.080	0.0000	Depth min.	0.632	0.506	8.973	0.0000
Distance from bank	–9.901	–0.148	–2.855	0.0046	Organic	0.020	0.150	2.713	0.0071
Depth min.	23.021	1.073	5.700	0.0000	Factor I	–0.093	–0.169	–3.034	0.0027
Depth max.	–22.914	–1.238	–5.967	0.0000					
Factor II	–1.482	–0.155	–2.417	0.0163					
Factor IV	1.189	0.206	3.186	0.0016					
Organic	–0.516	–0.218	–3.213	0.0015					
Anodonta cygnea									
Density (R^2 = 0.44043)					Condition (R^2 = 0.05126)				
Distance from bank	13.911	0.558	23.745	0.0000	Depth max.	–0.441	–0.211	–3.298	0.0011
Depth min.	–4.240	–0.115	–4.782	0.0000	Factor II	–0.309	–0.355	–5.089	0.0000
Depth max.	–1.318	–0.035	–1.744	0.0821					
Factor II	2.533	0.162	8.802	0.0000					
Organic	–0.429	–0.916	–38.287	0.0000					
Pseudanodonta complanata									
Density (R^2 = 0.99779)									
Macrophytes	–3.528	–1.164	–27.030	0.0000					
Depth min.	31.608	2.562	37.479	0.0000					
Depth max.	–27.878	–3.218	–42.079	0.0000					
Particles L	–3.062	–1.025	–35.612	0.0000					
Particles M	1.691	0.349	11.879	0.0000					
Organic	–0.026	–0.049	–3.718	0.0019					
Unio crassus									
Density (R^2 = 0.24037)									
Organic	0.117	–0.793	2.754	0.0110					
Factor II	–0.281	–0.608	–2.112	0.0453					

b – regression coefficient; t° – value of t-Student function; p – statistical significance; β – beta coefficient however, these factors affected its condition negatively. *U. tumidus* preferred river sections of moderate current, bays, depressions and shallows located outside the main current. It avoided deep places. There was a negative correlation between the maximum depth and the density and condition (Table 9). The species formed dense beds, sometimes extending for several dozen metres, in lenithic sections of the river, meanders, places where fertile silt accumulated, or in belts of reed vegetation where sediments were deposited (positive correlation with the "macrophyte" factor). The condition of *U. tumidus* was positively affected by both the presence of macrophytes and a slight depth of the river, and negatively by a large depth. It was infrequent in sandy deposits of the Pilica tributaries (23.8% localities) and common (64.1% localities) but not abundant (16.8% total collection) in the Sulejowski Reservoir. It occurred on sandy bottom in shallow, near-shore parts of the reservoir and in a deeper littoral, outside the zone of accumulation of loose silt, to the depth of 4 m. Likewise, it was rather frequent and abundant in the oxbows (33.3% localities) connected with the river.

A typical species of the floodplain water bodies is *A. cygnea*. It occurred in stagnant or very slowly flowing waters. It was a clear dominant in the oxbows, found at 20 (95.2%) localities and constituting 54% total collection. Usually it was found in entire oxbows, both in the zone of connection with the river and in the peripheral parts. It chose muddy or sandy deposits with a superficial layer of mineralised silt, reaching its highest densities in fine-grained sediments (0.063–0.125 mm, FACTOR II). Sediments of great thickness, accumulating in the central parts of oxbows, had a limiting effect, as well as thick layers of detritus with plant remnants, e.g. sunken branches (ORGANIC). It inhabited near-shore, shallow parts of the bottom, devoid of aquatic vegetation. A negative correlation was found between the presence of submerged macrophytes and the density and condition of the species (Table 9). Except one empty shell, no *A. cygnea* was found in the oxbows remote from the river (Kurnędz, loc. 37) and in very muddy water bodies (locs 80, 81). It was much less frequent and less abundant in the Sulejowski Reservoir (20.5% localities), where it was sometimes found at depths up to 4.5 m. In such places, the bottom was covered with only a thin mud layer. It avoided loose, black, unmineralised sediments. *A. cygnea* was sporadically found also in the Pilica, as single individuals in sections located close to the oxbows connected with the river, where it could penetrate with flood waters. It inhabited also a muddy bay (Kurnędz, loc. 38b), in the zone of stagnant water, where it formed a dense aggregation in the area of accumulation of the sediment brought by the river.

U. crassus and *P. complanata* are typically fluviatile unionid species, preferring clear water courses with sandy or gravelly bottom. In the study area they were very rare and not abundant (pp. 119 & 128). In the mid section of the Pilica *P. complanata* was most often found in organic-poor, sandy, medium-grained sediments (positive correlation with FACTOR IV and negative with FACTOR II). It avoided clumps of macrophytes and deep places (Table 9). It was present also in mouth sections of the tributaries: Czarna Włoszczowska and Czarna Konecka. As a rule *P. complanata* accompanied other unionid species in rather shallow places of the shore part of the river, outside macrophyte clumps. Single specimens of *P. complanata* were found in an oxbow permanently connected to the Pilica.

Unio crassus, present in the mid section of the Pilica, was more abundant in sandy tributaries. It was found both near the shores in shallows and sloping bottom, as well as in the current. It avoided fine-grained, organic-rich muddy deposits (Table 9). Because of the scarcity of data on the condition of both species and the zero value of variance, the variables proved to be strongly redundant. This prevented a detailed evaluation of the habitat preferences and the effect of habitat factors on the condition of the bivalves.

The rarest species in the study area was *A. cygnea* f. *cygnea*, found in one locality only (loc. 102), in sandy sediments of the shore zone of the mouth of the Pilica. The bivalves occurred in a clayey-muddy, shallow depression at a high bank overgrown with willows. The bed was limited to a belt 4 m long and 30 cm wide, in a lenithic section of the Pilica where 23 individuals were found within 15 minutes. It was sporadic in sandy parts of the bottom. Individuals of *A. cygnea* f. *cygnea* were accompanied by *U. pictorum*, and (in

Table 10. Content of dry seston in the Pilica in mgl^{-1} in 1997–1998

localities	summer		autumn		winter		spring	
	a	b	a	b	a	b	a	b
Maluszyn (loc. 15)	78.59	12.02	9.71	7.62	7.51	6.09	11.98	8.74
Placówka (loc. 29)	14.98	8.21	10.59	8.32	4.95	4.02	12.73	8.63
Kurnędz (loc. 38)	7.23	4.53	5.54	2.57	5.25	4.47	8.91	5.95
Sulejowski R. (loc. 56)	6.29	3.31	5.15	2.40	2.65	1.93	4.29	1.71
Smardzewice (loc. 57)	9.59	2.12	9.18	2.50	1.41	1.22	5.29	2.01
Gapinin (loc. 82)	38.29	3.19	8.71	6.89	1.70	1.21	12.68	5.82

a – total seston; b – inorganic seston

masses) by *Viviparus viviparus*. All the individuals were covered by aggregations of zebra mussels.

4.2.2. Seston content

The results of analyses of seston content in the Pilica, performed four times (summer, autumn, winter 1997, spring 1998) at five localities in the river, located above and below the Sulejowski Reservoir (Table 10) indicate that larger quantities of suspension are carried by the river in its upper and mid sections than below the reservoir. An especially low seston content was noted below the dam of the reservoir in Smardzewice (2.65 mgl^{-1} in winter to 6.21 mgl^{-1} in summer). The trend was evident in the samples from all seasons of the year. A slightly higher quantity of suspension in the water was observed in the further part of the lower section (38.29 mgl^{-1} – summer, loc. 79, Gapinin). The highest quantity of total seston (78.59 mgl^{-1}) was recorded in summer in Maluszyn (loc. 15). Lower seston values, noted in Kurnędz (7.23 mgl^{-1}), could result from the localisation of the sampling point. It was located just below a wide arch of the river, where the suspension carried by the river sedimented, as indicated by thick layers of silt. This was also the place of occurrence of a big bed of unionids, filtering considerable amounts of seston. Based on the results of water analysis of 1993–1997 by PIOŚ (Tables 2, 4) it can be said that the suspension level in the upper and mid sections ranged from 10 to 40 mgl^{-1} and was clearly higher (>50 mgl^{-1}) over the section Szczekociny-Maluszyn, and periodically also in Wymysłów (94th km of the river). The highest seston content in the four sampling points in the Sulejowski Reservoir did not exceed 30 mgl^{-1} (Report on the state of environment in Piotrków voivodeship in 1996). In the lower section of the Pilica River it remained at a level corresponding to I and II water quality class and did not exceed 30 mgl^{-1} (Table 2).

Based on multiple regression explaining the effect of seston on the condition of unionids in the Pilica (Table 10), it was found that preferences of the two discussed species were different. Independent variables were parameters of the group of habitat factors: "total seston", "inorganic seston" and "organic seston". There was a significant, positive correlation between the presence of total seston and its inorganic fraction, and the density of *U. pictorum* (Table 10). This may indicate a low food selectivity of the species. Due to this *U. pictorum* can exist also in the lower section of the river, in spite of smaller resources of allochthonous organic matter (detritus). In the case of the second most common species in the Pilica – *U. tumidus* – a significant dependence was found between the condition of the bivalves and the presence of organic fraction in the seston (Table 11). This may suggest that one of the factors limiting the occurrence of *U. tumidus* is the poverty of organic suspension and fine detritus. It may explain the absence of *U. tumidus* in the lower section of the Pilica.

4.2.3. Physico-chemical, hydrobiological and bacteriological water pollution

An attempt was made at estimating the effect of selected indices of water quality on the condition of three unionid species characteristic of the Pilica. The dependent variable was the condition coefficient CC. The independent variables were 30 partial variables of the group of water quality indices and long-term means: suspension, nitrite nitrogen, chlorophyll a, total phosphorus, BOD_5 and coli titre.

For *U. pictorum* the multiple regression analysis revealed a significantly negative effect of chlorophyll a on the condition of the bivalve in the Pilica in 1995, when an especially high, standard-exceeding level of this factor in the whole lower section of the river was noted (Table 12). In the control point of PIOŚ in Niemojewice, it amounted to 71.2 mgl^{-1} (standard for water quality class admits up to 30 mgl^{-1} – Table 2). It was also demonstrated that an increased level of nitrite nitrogen (0.03–0.06 mg NNO_2 l^{-1}) observed in the Pilica, as well as a high content of total suspension (1995) (Table 2), were tolerated and did not affect the condition of *U. pictorum* negatively (Table 12). Calculations based on long-term mean values also confirmed the tolerance of *U. pictorum* to the level of nitrite nitrogen in the water, corresponding to quality

Table 11. Multiple regression – effect of seston on unionid condition

seston	b	β	t°	p
		Unio pictorum		
		Condition (R^2 = 0.14949)		
total seston	0.009	0.387	4.086	0.0001
inorganic seston	0.012	0.383	4.040	0.0001
		Unio tumidus		
		Condition (R^2 = 0.16902)		
organic seston	0.043	0.411	3.800	0.0003

b – regression coefficient; t° – value of t–Student function; p – statistical significance; β – beta coefficient

Table 12. Multiple regression – effect of water quality indices on unionid condition

Partial variable	b	β	t°	p	Long-term means	b	β	t°	p
					Unio pictorum				
	Density (R^2 = 0.27541)					Condition (R^2 = 0.18126)			
Suspension 1994	0.012	0.288	4.768	0.0000	Nitrite N	8.147	0.291	4.467	0.0000
Nitrite N 1996	7.609	0.418	6.113	0.0000	BOD_5	–0.077	–0.422	–6.478	0.0000
Chlorophyll a 1995	–0.004	–0.369	–5.202	0.0000					
					Unio tumidus				
	Density (R^2 = 0.51444)					Condition (R^2 = 0.51668)			
Chlorophyll a 1995	–0.007	–0.121	–2.334	0.0206	Suspension	0.022	0.651	4.691	0.0000
BOD_5 1993	0.197	0.738	14.208	0.0000	Nitrite N	–42.556	–1.378	–8.722	0.0000
					Phosphorus	12.122	1.240	10.330	0.0000
					Anodonta anatina				
	Density (R^2 = 0.38199)					Condition (R^2 = 0.36655)			
Suspension 1994	0.015	0.145	2.058	0.0416	Suspension	0.006	0.154	2.152	0.0333
Chlorophyll a 1995	0.010	0.631	8.961	0.0000	Chlorophyll a	0.007	0.622	8.672	0.0000

b – regression coefficient; t° – value of t-Student function; p – statistical significance; β – beta coefficient

class III (Tables 2, 12). At the same time a negative effect of a low content of dissolved oxygen, manifest as a high BOD_5 level (Table 12), on the condition of *U. pictorum* was found. The value of this index in the lower section of the Pilica ranged from 8 to 12 mg O_2 l^{-1} (Tables 2, 4).

It was observed that *A. anatina* tolerated high concentrations of suspension in the water, both for especially high concentrations observed in 1994 (Table 2) and for the long-term mean (Table 12). It is the only species tolerating also high concentrations of chlorophyll a, exceeding 30 mgl^{-1} (Table 12).

Multiple regression between the long-term means of water quality indices and condition of *U. tumidus* indicates that the species well tolerates high concentrations of total phosphorus (0.25–0.4 mgl^{-1}) and a high level of suspension in the water (30–50 mgl^{-1} – Table 12). However, a highly negative correlation was found with nitrite nitrogen (Table 12). The nitrogen level corresponding to class III of water quality (0.03–0.06 mgl^{-1}) limits the condition of the bivalve. Likewise, the increased level of chlorophyll a calculated for 1995 (Table 2) limits the condition of *U. tumidus* (Table 12). On the contrary, a periodically low oxygen content observed in 1993 in the uppermost section of the Pilica (Table 2), manifest as increased BOD_5 level, was tolerated (Table 12).

Bacteriological pollution of water expressed as high values of coli titre, observed in the whole river (Table 2) was tolerated by the bivalves and had no significant effect on the condition of *U. pictorum, U. tumidus* and *A. anatina* (Table 12).

4.3. SELECTED CHARACTERISTICS OF UNIONID POPULATIONS

4.3.1. Age structure

Based on uni-variate analysis, four unionid species living in various types of habitats were found to differ in their age structure (Tables 13, 14).

The age of individuals of *U. pictorum* collected in the Pilica catchment area ranged from 1 to 8 years. The highest mean age was found in the mid Pilica (4.72 years) and it differed significantly from that of the individuals from the lower section of the river (3.01 years) (Table 14). In contrast to the age structure of *U. pictorum* in the mid Pilica, of a distribution close to normal, in the localities of the lower Pilica and the Sulejowski Reservoir, there was a dominance of specimens 3 years old and a much lower proportion of bivalves of older age classes (Fig. 23a). In the remaining habitats the age assumed intermediate values.

The oldest collected specimens of *U. tumidus* were 9 years old. Variance analysis (Table 14) showed that the mean age of the bivalves from the mid Pilica (4.62 years) and the tributaries (4.36 years) was statistically significantly higher than the age of the bivalves inhabiting stagnant water bodies (3.30 years). The distribution of age in the species in various habitats was similar to that of *U. pictorum*. It should be stressed, however, that the population from the Sulejowski Reservoir was clearly unstable regarding age. Specimens two years old constituted the dominant class, a much less numerous class included individuals of 3–5 years, while older bivalves occurred only sporadically (Fig. 23b).

The mean age of *A. anatina* from the mid Pilica (3.78 years) and the tributaries (3.40 years) differed significantly from the mean age of this species in the Sulejowski Reservoir (2.81 years) and the oxbows (1.50 year) (Table 14). The low value for the populations from the oxbows could result from the scarcity of material (Table 13). The distribution of age classes of *A. anatina* was similar among habitats. In all of them there was a dominance of specimens of 2–4 years (Fig. 24a), the oldest group including individuals 7 years old.

Table 13. Variance analysis of age factor of five unionid species for particular types of habitats

source of variation	sum of squares of deviations	df	mean square	F	p
Unio pictorum					
1. Variation between habitats	447.009	4	111.752	56.322	0.0000
2. Variation within habitats	2416.702	1218	1.984		
3. Total variation	2863.711	1222			
Unio tumidus					
1. Variation between habitats	278.086	4	69.521	33.896	0.0000
2. Variation within habitats	1322.913	645	2.051		
3. Total variation	1600.998	649			
Unio crassus					
1. Variation between habitats	0.102	1	0.102	0.123	0.7270
2. Variation within habitats	40.721	49	0.831		
3. Total variation	40.824	50			
Anodonta anatina					
1. Variation between habitats	105.747	4	26.437	15.888	0.0000
2. Variation within habitats	953.445	573	1.664		
3. Total variation	1059.192	577			
Anodonta cygnea					
1. Variation between habitats	148.975	2	74.487	46.755	0.0000
2. Variation within habitats	611.769	384	1.593		
3. Total variation	760.744	386			

F – value of Snedecor function; p – probability of acceptance of null hypothesis; df – degrees of freedom

Table 14. Variation in mean age of particular unionid species among different types of habitats, insignificant values in Tukey test are underlined with continuons line

Species						
1. *Unio pictorum*	a	2	4	3	5	1
	b	3.0	3.7	3.7	4.0	4.7
	c	365	94	129	406	229
2. *Unio tumidus*	a	5	4	3	1	
	b	3.3	3.3	4.4	4.6	
	c	246	55	42	305	
3. *Anodonta anatina*	a	4	5	2	3	1
	b	1.5	2.8	2.9	3.4	3.8
	c	6	130	210	77	155
4. *Anodonta cygnea* f. *cellensis*	a	4	5	1		
	b	2.9	3.1	4.7		
	c	301	32	54		

a – habitat types: 1 – middle part of Pilica River; 2 – lower part of Pilica River; 3 – tributaries; 4 – oxbows; 5 – Sulejowski Reservoir
b – age, mean value; c – number of specimens

The oldest unionid individuals, 9 years old, were *A. cygnea* f. *cellensis* collected in a river locality (Kurnędz, loc. 38) in the mid Pilica. Likewise, the highest mean age of that bivalve (4.70 years) was characteristic of specimens from the mid Pilica. It was significantly higher than the age reached by *A. cygnea* f. *cellensis* in the oxbows and the Sulejowski Reservoir (Table 14). The age structure of the population inhabiting oxbows showed a slight negative skewness, with the prevalence of individuals 3 years old. The least stable age

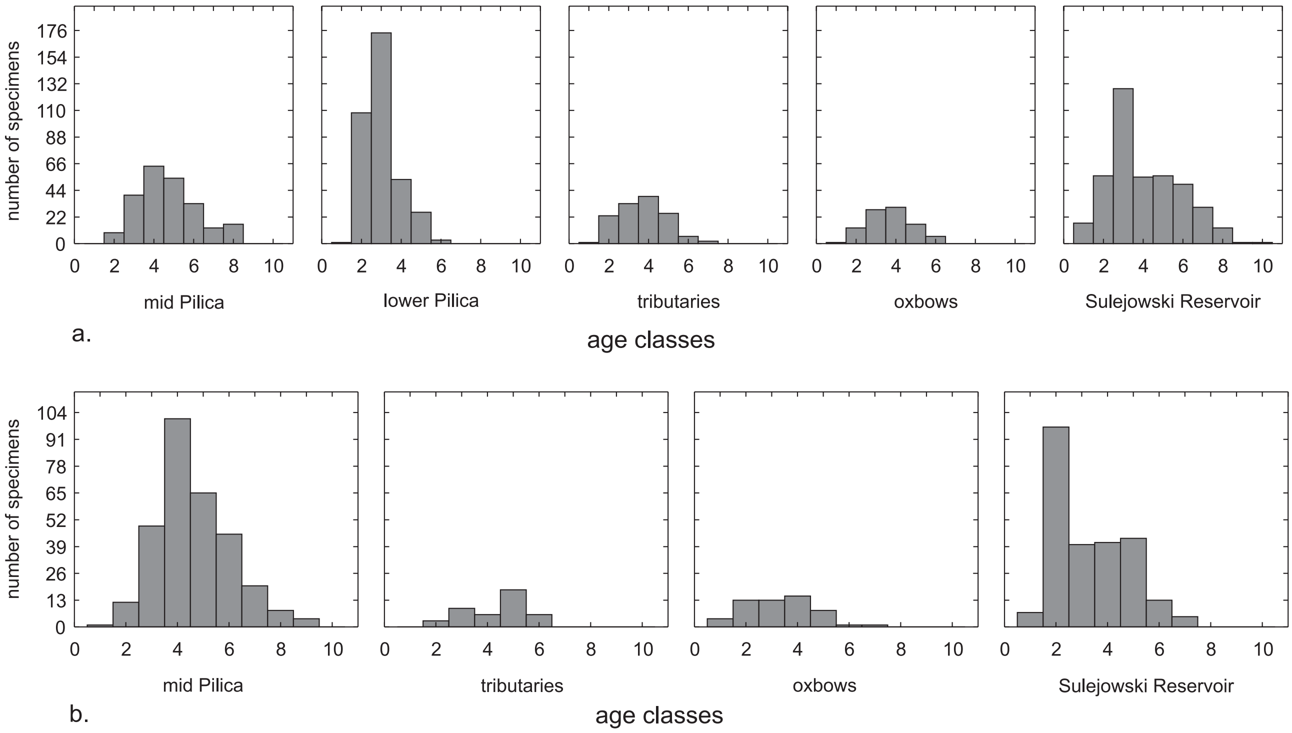

Fig. 23. Age structure: a – *Unio pictorum*, b – *Unio tumidus*

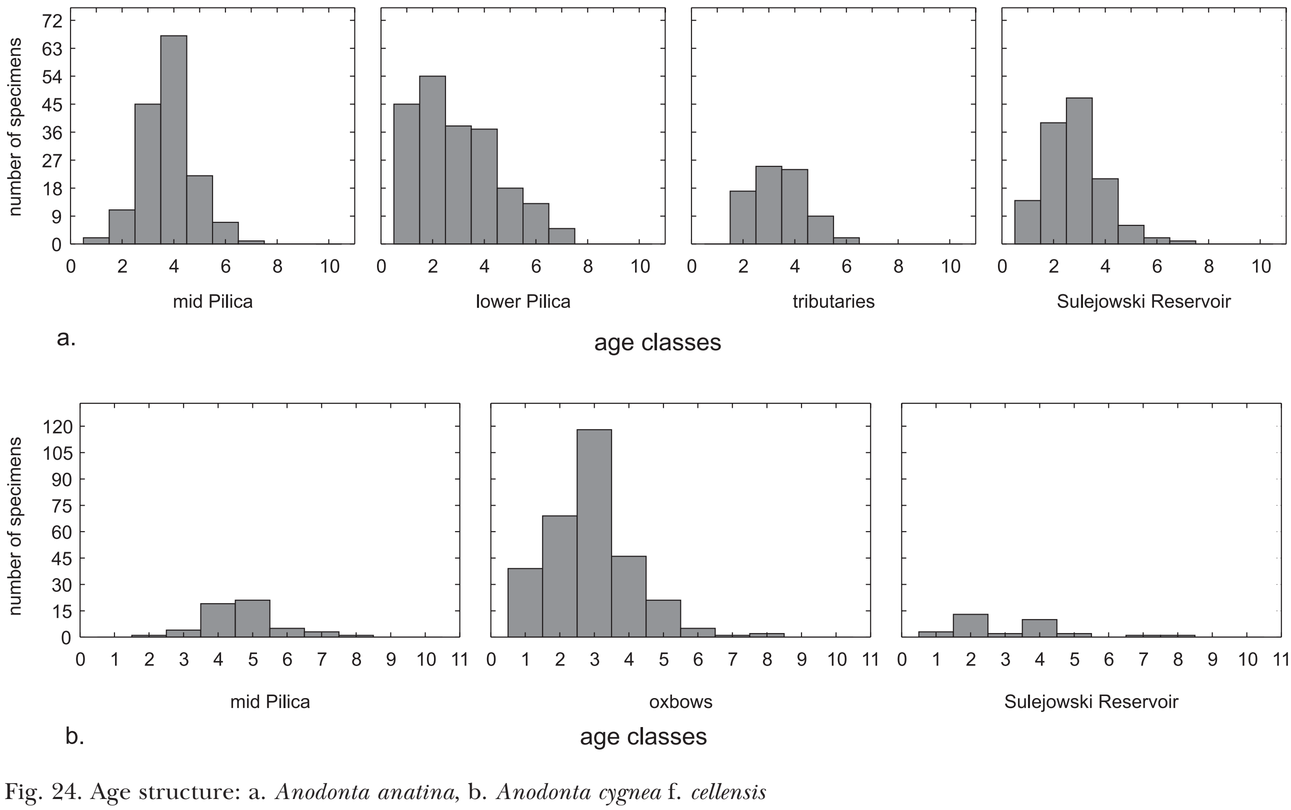

Fig. 24. Age structure: a. *Anodonta anatina*, b. *Anodonta cygnea* f. *cellensis*

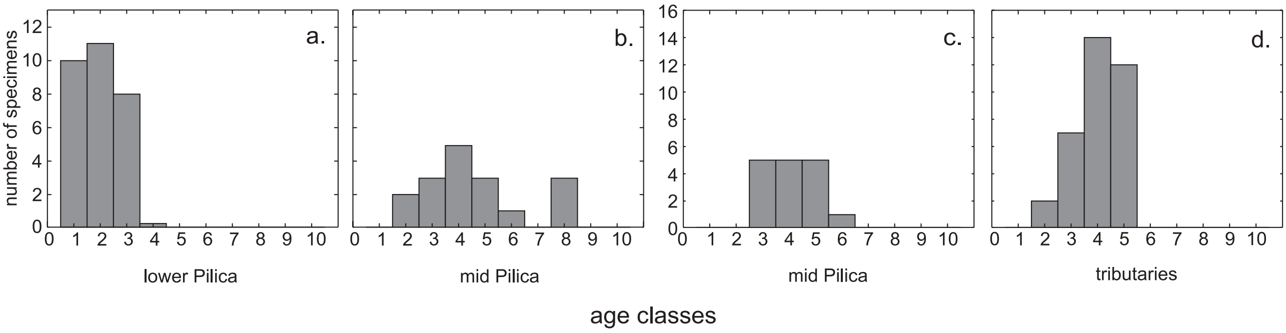

Fig. 25. Age structure: a. *Anodonta cygnea* f. *cygnea*, b. *Pseudanodonta complanata*, c, d. *Unio crassus*

structure was that of individuals from the Sulejowski Reservoir (Fig. 24b).

Because of the scarcity of data, the factor "age" was not analysed for species which are rare in the Pilica catchment area. Their age structure can be roughly estimated based on histograms (Fig. 25). The distribution of age classes of the rare form *A. cygnea* f. *cygnea* suggests that the species could have invaded the Pilica relatively recently, as indicated by the prevalence of young individuals (1–3 years old) and a complete absence of older specimens, of more than 4 years (Fig. 25a).

4.3.2. Variation of metric characters

Based on the analysis of the values of metric characters of both non-standardised data and measurements standardised with respect to age, and principal components distinguished on this basis (SHELL SIZE and SHELL SHAPE), the bivalves inhabiting various types of habitats proved to differ morphologically (Tables 21–28).

Unio pictorum

Populations of *U. pictorum* from the Pilica catchment area showed a differentiation in the following metric characters: length (L), height (H), shell convexity (C), height/length ratio (H/L) and convexity index (C/L), as well as shell mass (SM) and body mass (BM) in various types of habitats.

The mean shell length (±SD) for the analysed set (N = 801) was 63.45±12.84 mm; minimum-maximum range being 19.00–99.90 mm. The longest shells were those of the specimens from the mid Pilica (65.80±

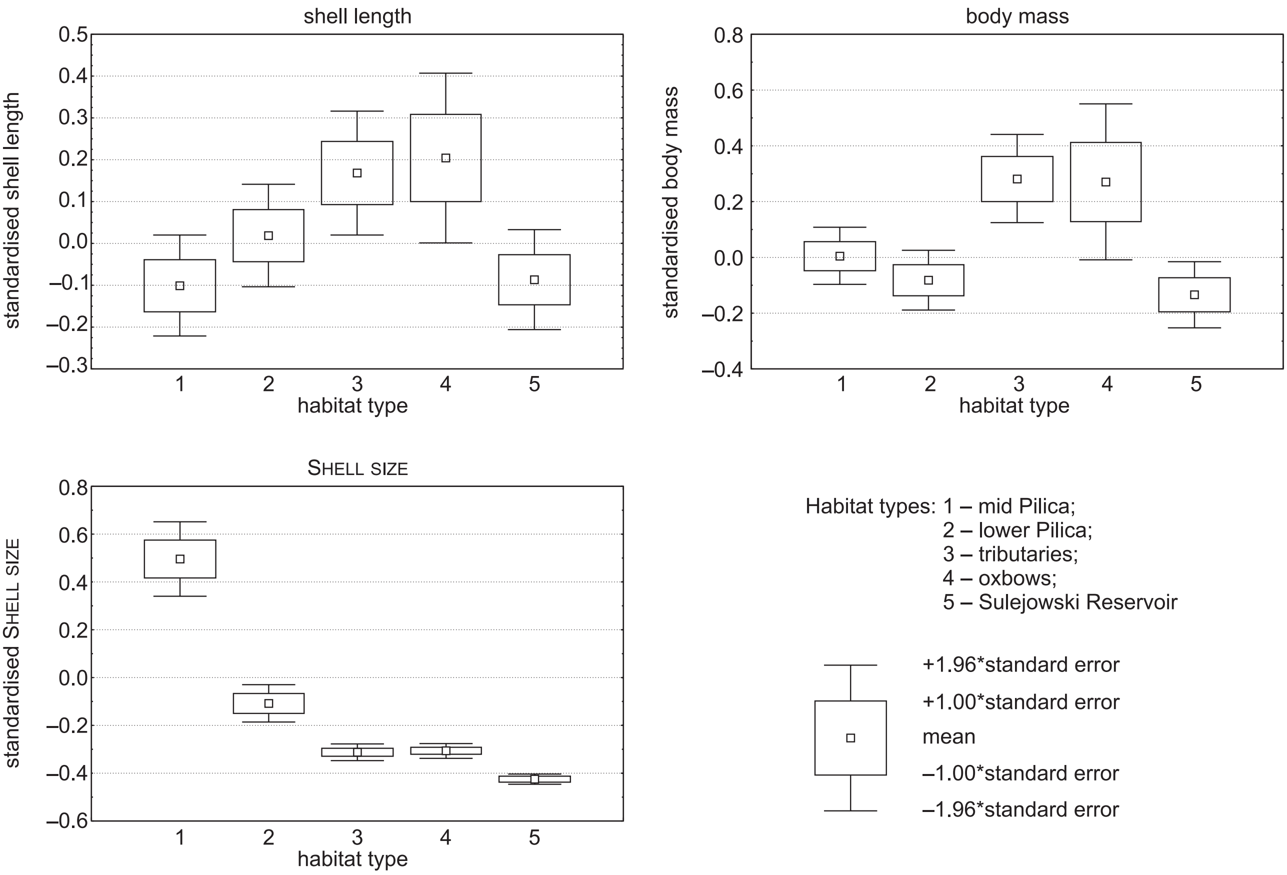

Fig. 26. Variation of metric characters of *Unio pictorum* in five types of habitats

Table 15. Metric characters of *Unio pictorum*

Character	H	N	Mean	SD	min.	max.	females	males
shell length (L) (mm)	1	121	65.8	12.17	30.0	92.8	67.0	64.3
	2	223	59.2	12.16	19.0	93.7	60.8	57.8
	3	123	64.0	10.81	25.0	90.0	63.7	64.0
	4	86	64.6	10.46	35.2	91.2	65.7	64.6
	5	248	65.4	14.50	22.3	99.9	68.5	62.4
total		**801**	**63.5**	**12.84**	**19.0**	**99.9**	**65.1**	**61.7**
shell height (H) (mm)	1	121	28.8	5.24	13.8	42.2	29.4	28.0
	2	223	25.2	5.03	9.0	41.9	25.9	24.6
	3	123	28.1	4.90	11.8	41.8	27.8	28.4
	4	86	28.1	4.53	15.6	42.8	26.7	27.3
	5	248	28.8	6.25	10.9	44.1	30.4	27.3
total		801	**27.6**	**5.60**	**9.0**	**44.1**	**28.4**	**26.8**
H/L	1	121	0.4	0.02	0.4	0.5		
	2	223	0.4	0.02	0.4	0.6		
	3	123	0.4	0.02	0.3	0.5		
	4	86	0.4	0.02	0.3	0.5		
	5	248	0.4	0.02	0.3	0.5		
total		**801**	**0.4**	**0.02**	**0.3**	**0.6**		
shell convexity (C) (mm)	1	121	20.0	3.84	9.2	28.2	20.3	19.5
	2	223	17.7	3.76	6.5	30.1	18.3	17.2
	3	123	19.7	3.82	6.9	27.0	19.6	19.8
	4	86	19.4	3.25	6.9	27.0	19.8	18.9
	5	248	20.3	4.32	7.7	32.1	21.3	19.3
total		**801**	**19.3**	**3.98**	**6.5**	**32.1**	**19.9**	**18.7**
C/L	1	121	0.3	0.02	0.2	0.4		
	2	223	0.3	0.02	0.2	0.4		
	3	123	0.3	0.01	0.3	0.3		
	4	86	0.3	0.02	0.3	0.4		
	5	248	0.3	0.02	0.3	0.4		
total		**801**	**0.3**	**0.02**	**0.2**	**0.4**		
shell mass (SM) (g)	1	121	11.4	5.78	1.0	34.9	11.7	11.0
	2	223	8.7	5.69	0.6	34.5	9.0	8.4
	3	123	10.5	5.15	0.8	30.2	10.3	10.8
	4	86	9.5	4.56	1.9	30.2	9.9	9.0
	5	248	11.1	6.40	0.4	40.5	12.5	9.8
total		**801**	**10.2**	**5.84**	**0.4**	**40.5**	**10.8**	**9.6**
body mass (BM) (g)	1	121	8.5	3.85	0.7	18.6	8.9	8.0
	2	223	5.9	3.60	0.4	20.4	6.5	5.3
	3	123	8.0	3.51	0.5	19.2	8.0	8.1
	4	86	8.0	4.01	1.3	20.0	8.9	6.9
	5	248	7.7	4.26	0.1	26.7	8.2	7.1
total		**801**	**7.4**	**3.99**	**0.1**	**26.7**	**7.2**	**6.9**

H – habitat: 1 – mid Pilica; 2 – lower Pilica; 3 – tributaries; 4 – oxbows; 5 – Sulejowski Reservoir; N – number of specimens; SD – standard deviation

12.17 mm), the shortest shells (60.80±12.16 mm) were found in the lower Pilica. The mean shell mass ±SD for the whole collection was 10.23±5.84 g (max. 40.50 g), the mean body mass was 7.40±3.99 g (max. 26.70 g) (Table 15).

The lowest values of non-standardised measurements of L, H, H/L, C and BM were those of the bivalves from the lower Pilica. They differed significantly from the values reached by *U. pictorum* in the other types of habitats. Standardised values of L, H and C showed no differences between the types of habitats (Table 25). The shell mass and the body mass had a different distribution of standardised and non-standardised measurements. Standardised mass values were the lowest in *U. pictorum* from the Sulejowski Reservoir and they differed significantly from the values for the individuals from the lower Pilica, whose shells were the heaviest (Fig. 26). Non-standardised data show a reverse distribution, the shells of *U. pictorum* from the lower Pilica being the lightest compared to those of the bivalves from other sections of the Pilica and from stagnant water bodies. The age stabilisation through standardisation indicates that the heaviest shells are those of individuals from river sections of high flow (Table 25) which is probably associated with counteracting displacement by water current. The observation is confirmed by the lowest shell mass of *U. pictorum* from the Sulejowski Reservoir, where the bivalves are not exposed to destructive action of the current.

When the age was excluded by standardisation, the principal component SHELL SIZE showed the bivalves from the Sulejowski Reservoir as the smallest, compared to significantly larger individuals in the Pilica, in both its mid and lower sections (Table 25, Fig. 26). The principal component SHELL SHAPE revealed statistically significant differences in the shell appearance between *U. pictorum* from water courses and stagnant water bodies (Table 25). Bivalves from the Pilica and its tributaries were smaller than those from oxbows and the Sulejowski Reservoir. Besides, the shells of the lower Pilica population are slender and flat (H/L = 0.42, C/L = 0.29), while those of the population from the Sulejowski Reservoir are stout and convex (H/L = 0.49, C/L = 0.31).

Based on the variance analysis of metric characters of *U. pictorum* a clear differentiation of most linear parameters of the shell, as well as shell mass and body mass between the sexes was found (from p<0.04 to p = 0.000 for various characters) (Table 21). The mean values of length, height, convexity, shell mass and body mass were always higher for females (Table 15).

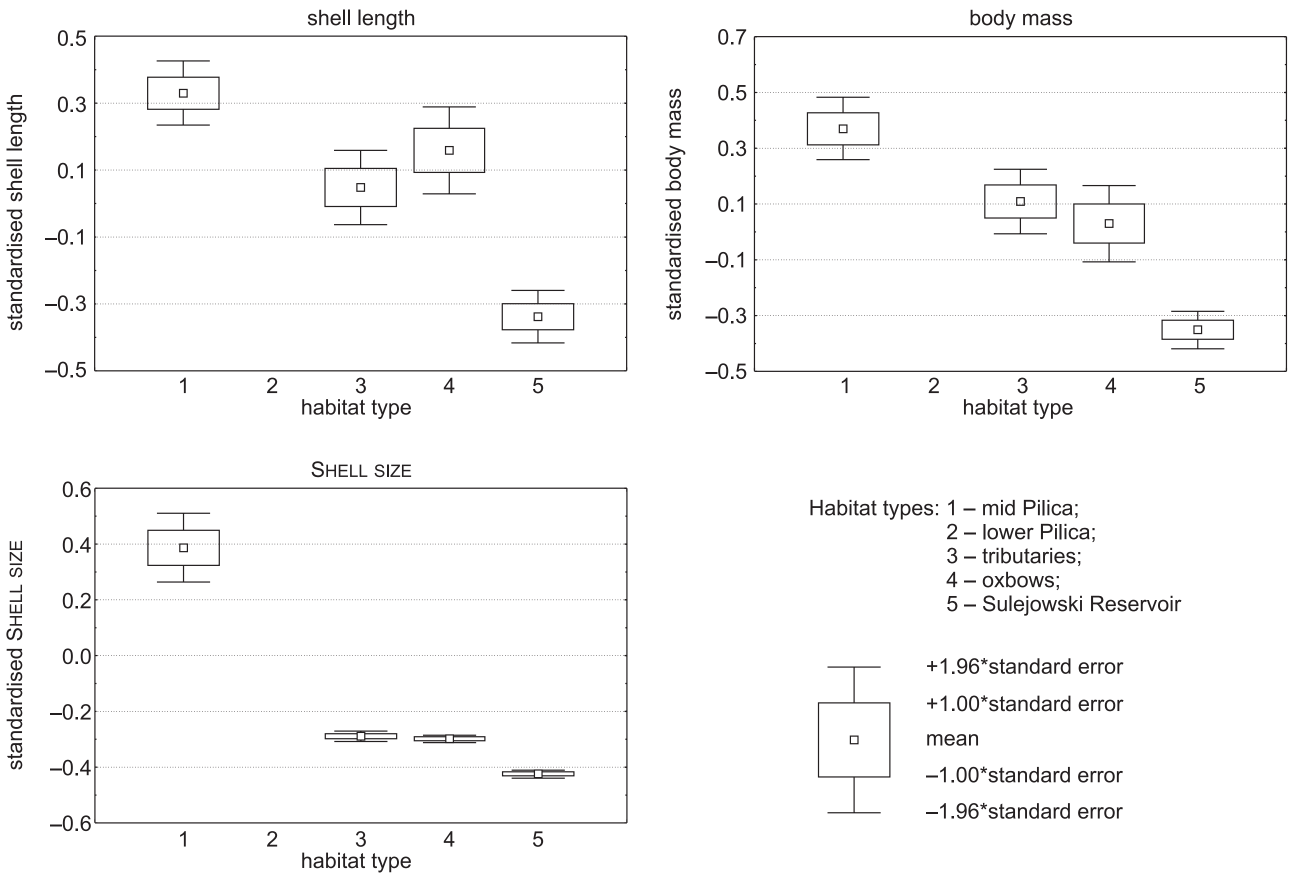

Fig. 27. Variation of metric characters of *Unio tumidus* in four types of habitats

A poor interaction was found for the shell height which suggests that in each sex it is differently affected by habitat (Table 21).

Unio tumidus

Populations of *U. tumidus* from the Pilica catchment area showed a significant variation in their metric characters between various habitats.

The mean shell length (±SD) for the analysed set (N = 364) was 66.04±12.41 mm; the minimum-maximum range was 20.20–96.00 mm. The shortest shells were those from the Sulejowski Reservoir where the mean length was 60.47±12.38 mm, the longest (70.49±11.06 mm) were found in the mid Pilica. The mean shell mass for the whole collection (±SD) was 15.45±8.87 g (maximum 52.20 g), the mean body mass was 8.69±4.64 g (maximum 26.50 g) (Table 16).

Table 16. Metric characters of *Unio tumidus* (differences between sexes statistically insignificant, see Table 21)

Character	H	N	Mean	SD	min.	max.
shell length (L)	1	176	70.5	11.07	36.9	96.0
(mm)	3	41	65.8	10.39	23.2	82.8
	4	49	61.4	12.70	20.2	93.7
	5	98	60.5	12.38	20.2	86.1
total		**363**	**66.0**	**12.42**	**20.2**	**96.0**
shell height (H)	1	176	34.4	5.26	20.2	48.7
(mm)	3	41	33.2	5.07	13.8	40.9
	4	49	30.2	5.91	10.5	45.6
	5	98	29.9	5.90	11.4	40.3
total		**363**	**32.5**	**5.87**	**10.5**	**48.7**
H/L	1	176	0.5	0.02	0.4	0.6
	3	41	0.5	0.02	0.5	0.6
	4	49	0.5	0.02	0.5	0.6
	5	98	0.5	0.02	0.4	0.6
total		**363**	**0.5**	**0.02**	**0.4**	**0.6**
shell convexity (C)	1	176	23.0	3.62	11.4	32.5
(mm)	3	41	22.8	4.05	9.1	28.0
	4	48	20.3	3.91	5.0	32.3
	5	98	20.8	3.85	8.0	28.9
total		**363**	**22.0**	**3.92**	**5.0**	**32.5**
C/L	1	176	0.3	0.02	0.2	0.4
	3	41	0.3	0.02	0.3	0.4
	4	48	0.3	0.02	0.2	0.4
	5	98	0.3	0.02	0.3	0.4
total		**363**	**0.3**	**0.02**	**0.2**	**0.4**
shell mass (SM)	1	176	17.8	9.11	2.9	51.8
(g)	3	41	17.4	8.30	1.1	34.7
	4	49	11.7	9.41	0.5	52.2
	5	98	12.4	6.57	0.6	33.8
total		**363**	**15.4**	**8.88**	**0.5**	**52.2**
body mass (BM)	1	176	10.6	4.55	1.5	26.5
(g)	3	41	9.4	3.81	0.5	15.1
	4	49	7.1	4.58	0.2	21.1
	5	98	5.8	3.24	0.2	14.3
total		**363**	**8.7**	**4.64**	**0.2**	**26.5**

H – habitat: 1 – mid Pilica; 3 – tributaries; 4 – oxbows; 5 – Sulejowski Reservoir; N – number of specimens; SD – standard deviation

The differentiation of linear parameters of the shell, as well as shell and body mass, and also of the principal components SHELL SHAPE and SHELL SIZE in four types of habitats (1, 3, 4, 5) where *U. tumidus* was abundant, showed a similar variation for both non-standardised and standardised measurements (Table 26). This indicates a lack of effect of the age factor on the growth of the bivalves in particular habitat types.

The highest values of L, H, SM and BM were reached by *U. tumidus* from the mid Pilica and the tributaries, the lowest – by individuals from the stagnant waters (Table 26, Fig. 27). The analysis of height/length ratio (H/L) and convexity index (C/L) revealed significant differences in the shell proportions between habitats. In the tributaries and the Sulejowski Reservoir the shells were stout (H/L = 0.50) and convex (C/L = 0.34). More flattened shells were found in the mid Pilica and the oxbows (C/L = 0.32) (Table 26). The smallest individuals, as described by the principal component SHELL SIZE, came from the Sulejowski Reservoir, the largest – from the mid Pilica (Fig. 27).

Variance analysis showed no statistically significant differences between the sexes, in any of the shell parameters, including convexity (Table 22). However, there was a weak interaction in the distribution of convexity index (C/L) between the types of habitats and sex (Table 22) which implies that each sex adopts a different growth strategy in different types of habitat.

Anodonta anatina

Populations of *A. anatina* showed a significant differentiation of metric shell characters and mass in the Pilica catchment area.

The mean shell length (±SD) for the entire collection (N=358) was 74.78±14.69 mm, the range being 19.10–112.3 mm. Specimens with the shortest shells (61.70±11.32 mm) were found in the Sulejowski Reservoir, the longest-shelled specimens were those from the lower Pilica (73.63±13.80 mm). The mean shell mass for the entire collection was 9.03±7.68 g (max. 17.0 g), the mean body mass was 14.00±10.57 g (max. 24.30 g). The heaviest shells (13.26±9.08 g) and the largest body mass (18.24±12.94 g) were found in the lower Pilica (Table 17).

The variation of all the measured characters of *A. anatina* in four types of habitats (1, 2, 3, 5) was significant (Table 23), and its course was similar for standardised and non-standardised measurements (Table 27) which indicates that the age factor does not affect the increase in the values of the measured characters.

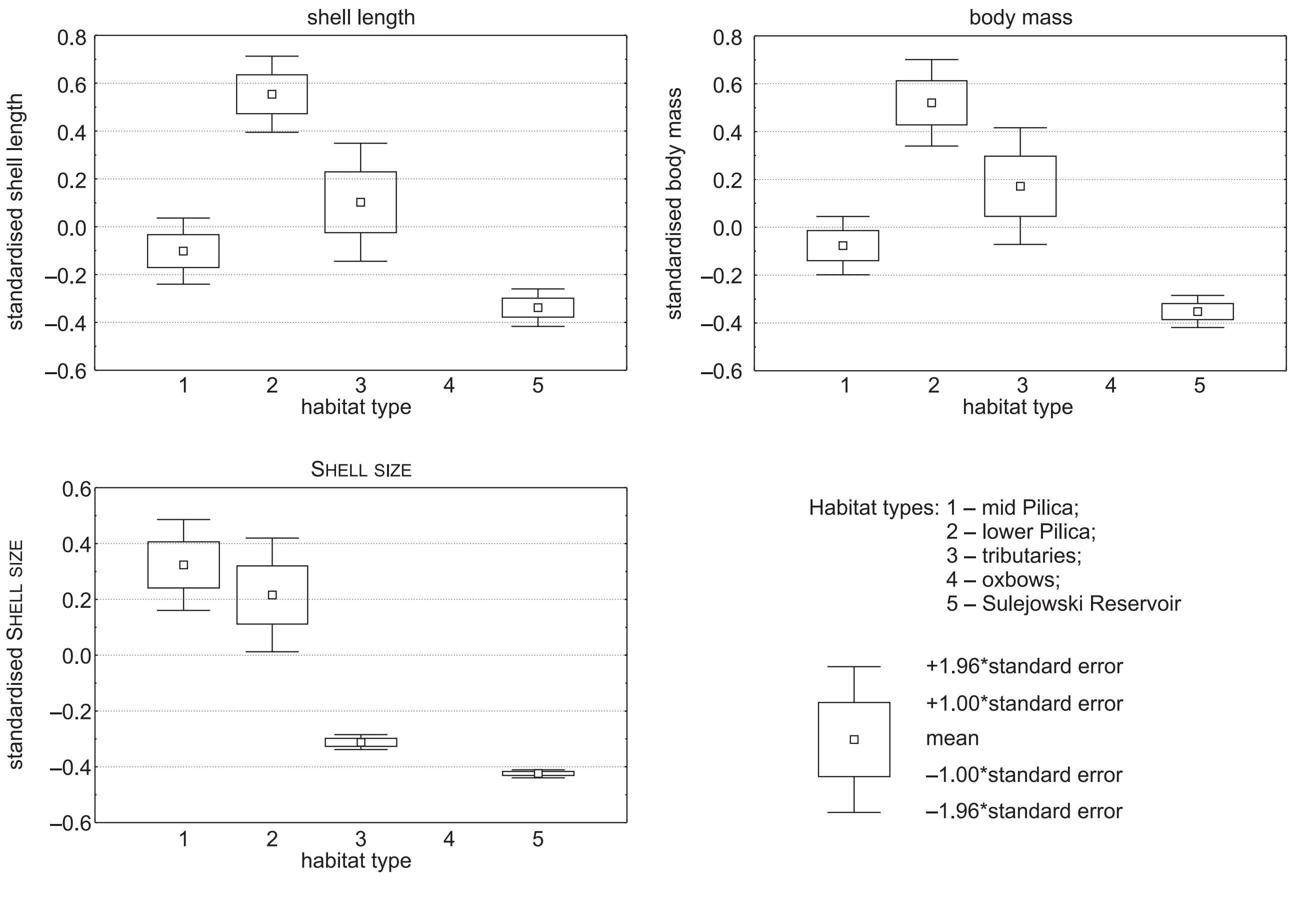

Fig. 28. Variation of metric characters of *Anodonta anatina* in four types of habitats

The lowest values of length (L), height (H), convexity (C), shell mass (SM) and body mass (BM) were characteristic of *A. anatina* from the Sulejowski Reservoir (Fig. 28). This was also reflected in the distribution of the principal component SHELL SIZE, which assumed the lowest values for the bivalves from the reservoir (Fig. 28). The highest values of the mentioned characters were characteristic of the unionids from the lower Pilica (Table 27). Individuals from the mid Pilica and the tributaries were characterised by significant differences in the H/L index; their shells were more slender (H/L = 0.50) compared to stouter specimens from the Sulejowski Reservoir (H/L = 0.55). At the same time *A. anatina* from the Sulejowski Reservoir had more flattened shells (convexity index C/L = 0.28) compared to the stout individuals from the lower Pilica (C/L = 0.31) (Table 27). The smallest shells of *A. anatina*, described by the principal compo-

Table 17. Metric characters of *Anodonta anatina*

Character	H	N	Mean	SD	min.	max.	females	males
shell length (L) (mm)	1	86	77.5	13.61	23.1	105.6	78.0	77.0
	2	152	78.9	14.54	19.1	112.3	81.4	77.2
	3	58	73.9	11.61	33.5	103.7	77.6	71.2
	5	62	61.7	11.33	22.1	87.2	68.9	57.7
total		**358**	**74.8**	**14.69**	**19.1**	**112.3**	**78.0**	**72.5**
shell height (H) (mm)	1	86	38.8	5.73	13.2	50.5	38.6	39.0
	2	152	42.6	7.76	10.6	61.3	43.3	42.1
	3	58	37.3	5.97	19.5	55.5	39.4	35.9
	5	62	34.1	6.43	15.0	47.3	37.7	32.1
total		**358**	**39.4**	**7.49**	**10.6**	**61.3**	**40.5**	**38.6**
H/L	1	86	0.5	0.03	0.4	0.6		
	2	152	0.5	0.03	0.4	0.6		
	3	58	0.5	0.03	0.4	0.6		
	5	62	0.6	0.04	0.4	0.7		
total		**358**	**0.5**	**0.04**	**0.4**	**0.7**		
shell convexity (C) (mm)	1	86	23.3	5.25	0.9	33.5	23.8	22.8
	2	152	25.3	6.12	3.2	43.0	27.2	24.0
	3	58	22.5	4.23	8.4	35.5	24.4	21.1
	5	62	17.3	4,00	6.0	27.1	20.0	15.9
total		**358**	**23.0**	**6.03**	**0.9**	**43.0**	**24.7**	**21.7**
C/L	1	86	0.3	0.04	0.0	0.5	0.3	0.3
	2	152	0.3	0.03	0.4	0.2	0.3	0.3
	3	58	0.3	0.03	0.2	0.4	0.3	0.3
	5	62	0.3	0.04	0.2	0.7	0.3	0.3
total		**358**	**0.3**	**0.04**	**0.0**	**0.7**	**0.3**	**0.3**
shell mass (SM) (g)	1	86	12.5	7.01	0.6	34.3		
	2	152	13.3	9.09	0.1	43.2		
	3	58	10.5	5.26	0.9	36.2		
	5	62	11.2	2.98	0.4	17.0		
total		**358**	**9.0**	**7.69**	**0.1**	**43.2**		
body mass (BM) (g)	1	86	13.9	6.86	0.4	34.2	15.3	12.5
	2	152	18.2	12.95	0.1	73.6	20.9	16.5
	3	58	11.8	6.26	1.1	30.8	15.0	9.5
	5	62	5.8	4.38	0.5	24.3	8.6	4.2
total		**358**	**14.0**	**10.58**	**0.1**	**73.6**	**16.5**	**12.2**

H – habitat: 1 – mid Pilica; 2 – lower Pilica; 3 – tributaries; 5 – Sulejowski Reservoir; N – number of specimens; SD – standard deviation nent SHELL SHAPE, were those from tributaries, the largest being those from the Sulejowski Reservoir (Table 27, Fig. 28).

Bi-variate analysis revealed highly significant differences in the values of L, H, C, BM and both the principal components between the sexes, both for non-standardised and standardised measurements ($p = 0.08$ to $p<0.000$ for particular characters) (Table 23). The values of a given character were always higher for females compared to males. For example, the mean shell length in females (for the entire collection) was 77.98±14.01 mm, while in males it was 72.47±14.01 mm (Table 17). There was also a clear difference in the shell convexity (C) and the convexity index (C/L) between the sexes. The females were more convex than the males, their mean value of C was 24.72 mm, that in males – 21.73 mm. The C/L index for females was 0.31, for males 0.29.

Usually both sexes adopted similar growth strategies in various kinds of habitats. Only the shell height showed poor interactions between the kind of habitat and sex (Table 23).

Anodonta cygnea f. *cellensis*

Populations of *A. c.* f. *cellensis* in the study area showed a significant variation in the studied metric characters between the habitat types.

The mean shell length (±SD) for the whole collection (N = 391) was 96.67±29.10 mm; the range being 31.80–177.5 mm. Specimens with the shortest shells (69.64±19.77 mm) were found in the Sulejowski Reservoir, the longest – in the mid Pilica (73.63±13.80 mm). The largest shells of *A. c.* f. *cellensis* were those of dead specimens found on the bottom of an emptied pond on the Gać River (loc. 70). The longest shell was 205 mm, the size of several other shells being 178–183 mm. The mean shell mass (±SD) of live bivalves was 9.03±7.68 g (maximum 82.2 g), the mean body mass 14.00±10.57 g (maximum 101.8 g) (Table 18).

The differences between the mean values of the measured characters of *A. c.* f. *cellensis* in the habitats where the species occurred (1, 4, 5) were significant for all the parameters (Table 24) and had a similar course for most non-standardised and standardised measurements. No significant differences were found in the studied parameters between the bivalves from different types of waters, for either non-standardised or standardised measurements. Like with *A. anatina* and *U. tumidus*, this testifies to the lack of effect of the age factor on the values of analysed characters.

The lowest mean values of length (L), height (H), convexity (C), shell mass (SM), body mass (BM) and the principal component SHELL SIZE were those of the individuals from the Sulejowski Reservoir (Table

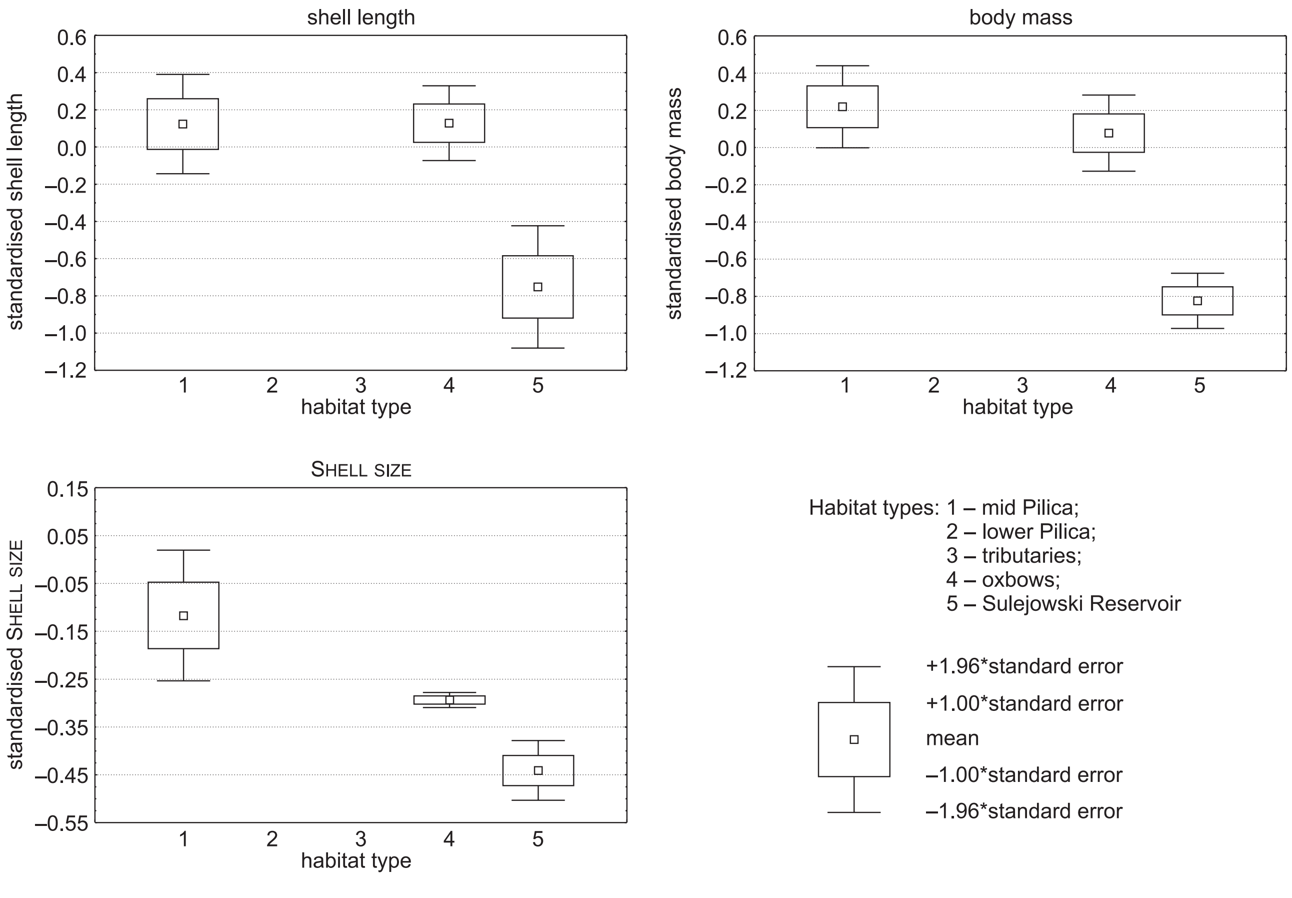

Fig. 29. Variation of metric characters of *Anodonta cygnea* f. *cellensis* in three types of habitats

Table 18. Metric characters of *Anodonta cygnea* f. *cellensis*

Character	H	N	Mean	SD	min.	max.
shell length (L)	1	58	103.1	17.26	47.1	140.5
(mm)	4	301	97.0	30.33	31.8	177.5
	5	32	69.6	19.76	37.8	125.1
total		**391**	**95.7**	**29.11**	**31.8**	**177.1**
shell height (H)	1	58	48.0	7.18	24.8	64.9
(mm)	4	204	44.5	13.91	16.3	85.2
	5	32	35.5	9.25	19.1	60.9
total		**294**	**44.2**	**12.816**	**16.3**	**85.2**
H/L	1	58	0.5	0.03	0.4	0.5
	4	204	0.5	0.03	0.4	0.6
	5	32	0.5	0.03	0.5	0.6
total		**294**	**0.5**	**0.03**	**0.4**	**0.6**
shell convexity (C)	1	58	26.6	6.23	12.5	44.3
(mm)	4	204	27.0	11.02	7.0	55.3
	5	32	17.7	7.36	6.0	40.0
total		**294**	**26.5**	**10.39**	**6.0**	**55.3**
C/L	1	58	0.3	0.03	0.2	0.4
	4	204	0.3	0.04	0.2	0.4
	5	32	0.2	0.04	0.2	0.3
total		**294**	**0.3**	**0.04**	**0.2**	**0.4**
shell mass (SM)	1	58	20.9	10.33	1.9	47.0
(g)	4	204	13.7	11.86	0.5	82.2
	5	32	5.9	5.81	0.7	27.7
total		**294**	**14.3**	**11.76**	**0.5**	**82.2**
body mass (BM)	1	58	21.2	8.30	3.1	46.2
(g)	4	204	22.6	21.17	0.7	101.8
	5	32	7.6	7.45	0.7	33.2
total		**294**	**20.7**	**18.74**	**0.7**	**101.8**

H – habitat: 1 – mid Pilica; 4 – oxbows; 5 – Sulejowski Reservoir; N – number of specimens; SD – standard deviation

28, Fig. 29). They differed significantly from the shells of *A. c.* f. *cellensis* from the mid Pilica and the oxbows, where the linear parameters of the shell and the body mass assumed the highest values. The analysis of non-standardised measurements of the shell mass revealed significant differences between the habitat types. The lightest shells were those of individuals from the Sulejowski Reservoir, the intermediate values were found in the oxbows, and the highest in the mid Pilica (Table 28). The values of the height/length ratio (H/L) (0.46–0.49) indicate that the shells from the river and the oxbows were more slender than those from the reservoir (H/L=0.51). Small shells described by the principal component SHELL SHAPE were found at a river locality, contrary to the large shells from the Sulejowski Reservoir and the oxbows (Table 28, Fig. 29).

Based on variance analysis significant differences were found between the sexes for such characters as convexity and convexity index (C/L) for non-standardised measurements, and height/length ratio (H/L) for standardised measurements (Table 24). They always assumed higher values for females. There was also a significant difference in the convexity index (C/L) between the sexes in various types of habitats (Table 24) which means that males and females adopt different growth strategies in various water bodies and courses.

Because of the scarcity of material the remaining unionid species were not tested with variance analysis. Their short morphometric characteristics are given below.

Anodonta cygnea f. *cygnea*

The shell size is based on measurements of 30 specimens collected in the lowermost section of the Pilica (loc. 102). The shell length was 93.03±15.82 mm, the range being 72.1–124.3 mm. The height/length ratio was higher than in f. *cellensis* and amounted to 0.52. The mean shell mass was 21.78±12.35 g (maximum 24.5 g), and the mean body mass 21.11±10.26 g (maxi-

Table 19. Metric characters of *Anodonta cygnea* f. *cygnea* and *Pseudanodonta complanata*

Anodonta cygnea f. *cygnea*						
Character	H	N	Mean	SD	min.	max.
shell length (mm) (L)	2	30	93.0	15.82	72.1	124.3
shell height (mm) (H)	2	30	48.7	8.50	28.7	67.4
H/L	2	30	0.5	0.03	0.4	0.6
shell convexity (mm) (C)	2	30	30.1	6.48	20.6	42.8
C/L	2	30	0.3	0.02	0.3	0.4
shell mass (g) (SM)	2	30	21.8	12.35	9.0	51.9
body mass (g) (BM)	2	30	21.1	10.26	9.3	52.6

Pseudanodonta complanata						
Character	S	N	Mean	SD	min.	max.
shell length (mm) (L)	1	25	61.8	14.29	38.5	94.2
	3	8	45.5	10.57	35.1	60.5
	4	2	44.8	14.35	34.6	54.9
total		**35**	**57.1**	**15.19**	**34.6**	**94.2**
shell height (mm) (H)	1	25	28.5	5.88	18.0	40.5
	3	8	21.1	3.54	17.2	26.5
	4	2	22.1	8.06	16.4	27.8
total		**35**	**26.5**	**6.32**	**16.4**	**40.5**
H/L	1	25	0.5	0.03	0.4	0.6
	3	8	0.5	0.04	0.4	0.6
	4	2	0.5	0.02	0.5	0.5
total		**35**	**0.5**	**0.04**	**0.4**	**0.6**
shell convexity (C)	1	25	18.1	4.36	9.7	25.5
(mm)	3	8	13.3	3.96	9.3	18.7
	4	2	12.3	5.73	8.2	16.3
total		**35**	**16.6**	**4.78**	**8.2**	**25.5**
C/L	1	25	0.3	0.02	0.2	0.3
	3	8	0.3	0.02	0.3	0.3
	4	2	0.3	0.04	0.2	0.3
total		**35**	**0.3**	**0.02**	**0.2**	**0.3**
shell mass (SM)	1	17	8.7	5.47	1.1	24.5
(g)	3	8	2.7	1.79	1.3	5.6
	4	2	2.4	2.19	0.8	3.9
total		**27**	**6.5**	**5.32**	**0.8**	**24.5**
body mass (BM)	1	17	10.0	5.28	1.6	18.9
(g)	3	8	3.2	2.11	1.3	6.3
	4	2	3.9	4.17	0.9	6.8
total		27	**7.5**	**5.46**	**0.9**	**18.9**

H – habitat: 1 – mid Pilica; 2 – lower Pilica; 3 – tributaries; 4 – oxbows; N – number of specimens; SD – standard deviation mum 18.9 g). Descriptive statistics for the measured characters in particular types of habitats are shown in Table 19.

Pseudanodonta complanata

The shell length values for the whole collection (N = 35) were 57.14±15.19 mm, the range being 34.6–94.2 mm. The bivalves from different habitats (1, 3, 4) differed in the mean values of their shell characters. The longest specimens were found in the mid Pilica (mean length 61.88±14.28), clearly smaller were those from the tributaries, and those from the oxbows were the smallest (44.75 mm). The mean shell mass was 6.45±5.31 mg, maximum 24.5 g, the mean body mass 7.51±5.46 g, maximum 18.9 g. Descriptive statistics for the measured parameters in particular habitats are listed in Table 19.

Unio crassus

The values of selected shell parameters of *U. crassus* were the following: mean shell length 60.62±10.88 mm, range 31.1–79.1 mm, mean shell mass 14.50±6.20 g, maximum 27.50 g, mean body mass 8.88±3.61 g, maximum 18.7 g. The values of all the metric characters in this species were higher in the mid Pilica than in the tributaries. The height/length ratio (H/L=0.52) was higher in the bivalves from the Pilica which means that they are somewhat stouter than those found in the tributaries (H/L=0.51). No significant differences between the sexes were found in the values of metric characters (Table 20). Descriptive statistics of the measured characters in particular kinds of habitats are given in Table 20.

4.3.3. Comparison of sexual dimorphism in members of the genera *Unio* and *Anodonta*

In thin-shelled bivalves of the genus *Anodonta* in which the shell mass is on an average by ca. 30% lower than the body mass (Table 29), the sexes do not differ in their shell mass. Due to the thin shell the females with glochidia-filled gills can increase their body volume; this is manifest as statistically significant differences in the shell convexity and convexity index, which in female *A. anatina* and *A. cygnea* assume higher values than in males.

Of the thick-shelled members of the genus *Unio* only *U. pictorum* (shell by 38% heavier than the body, Table 29) shows a sexual dimorphism manifest as significant differences in the shell and body mass, length, height and convexity of the shell (Tables 15, 21). In very thick-shelled species, *U. tumidus* and *U. crassus,* whose shells are by 43 and 45% heavier than body, respectively, no metric character displays a significant difference between males and females (Tables 16, 20, 22).

Table 20. Metric characters of *Unio crassus* (differences between sexes statistically insignificant)

Character	H	N	Mean	SD	min.	max.
shell length (L)	1	25	62.9	11.67	32.5	79.1
(mm)	3	35	59.0	10.14	31.1	74.5
total		**60**	**60.6**	**10.88**	**31.1**	**79.1**
shell height (H)	1	25	33.1	5.54	18.7	41.7
(mm)	3	35	30.2	4.75	17.2	37.3
total		**60**	**31.4**	**5.25**	**17.2**	**41.7**
H/L	1	25	0.5	0.03	0.5	0.6
	3	35	0.5	0.03	0.4	0.6
total		**60**	**0.5**	**0.03**	**0.4**	**0.6**
shell convexity (C)	1	25	22.4	4.94	10.5	28.3
(mm)	3	35	21.9	3.83	12.1	29.1
total		**60**	**22.1**	**4.29**	**10.5**	**29.1**
C/L	1	25	0.4	0.04	0.3	0.5
	3	35	0.4	0.02	0.3	0.4
total		**60**	**0.4**	**0.03**	**0.3**	**0.5**
shell mass (SM)	1	21	19.6	9.66	5.6	39.4
(g)	3	35	14.5	6.21	2.6	27.5
total		**56**	**16.4**	**8.00**	**2.6**	**39.4**
body mass (BM)	1	21	10.3	3.98	3.5	18.7
(g)	3	35	8.0	3.14	1.3	14.2
total		**56**	**8.9**	**3.62**	**1.3**	**18.7**

H – habitat: 1 – mid Pilica; 3 – tributaries; N – number of specimens; SD – standard deviation

Table 21. Bi-variate analysis of metric characters (ANOVA II) in *Unio pictorum* for sex and type of habitat

Source of variation	Non-standardised data					Age-standardised data				
	Sum of squares	df	Mean square	F	p	Sum of squares	df	Mean square	F	p
L										
1. Variation between sexes	1252.2	1	1252.2	8.051	0.005	8.7	1	8.7	9.760	0.002
2. Variation between habitats	5601.5	4	1400.4	9.004	0.000	14.9	4	3.7	4.174	0.002
3. Interactions	968.9	4	242.2	1.558	0.184	2.7	4	0.7	0.766	0.547
4. Unexplained variation	123020.1	791	155.5			704.9	791	0.9		
5. Total variation	131888.3	800				733.0	800			
H										
1. Variation between sexes	287.6	1	287.5	10.103	0.002	12.2	1	12.2	13.238	0.000
2. Variation between habitats	1813.2	4	453.3	15.928	0.000	7.3	4	1.8	1.985	0.095
3. Interactions	288.5	4	72.1	2.534	0.039	3.1	4	0.8	0.857	0.489
4. Unexplained variation	22511.5	791	28.5			726.6	791	0.9		
5. Total variation	25135.9	800				752.5	800			
H/L										
1. Variation between sexes	0.0004	1	0.0004	0.944	0.332	1.0	1	1.0	1.222	0.269
2. Variation between habitats	0.03	4	0.007	17.563	0.000	54.7	4	13.7	16.064	0.000
3. Interactions	0.003	4	0.0006	1.565	0.182	5.5	4	1.4	1.627	0.166
4. Unexplained variation	0.3	791	0.0004			673.8	791	0.9		
5. Total variation	0.4	800				735.5	800			
C										
1. Variation between sexes	1.4	1	1.4	9.963	0.002	10.8	1	10.8	12.013	0.001
2. Variation between habitats	8.6	4	2.1	14.727	0.000	6.9	4	1.7	1.913	0.106
3. Interactions	9.7	4	2.4	1.674	0.154	1.8	4	0.4	0.500	0.737
4. Unexplained variation	11488.1	791	14.5			711.2	791	0.9		
5. Total variation	12695.0	800				733.5	800			
C/L										
1. Variation between sexes	0.0003	1	0.0004	1.148	0.284	0.4	1	0.4	0.471	0.493
2. Variation between habitats	0.02	4	0.005	15.727	0.000	57.5	4	14.4	17.322	0.000
3. Interactions	0.0006	4	0.0002	0.526	0.717	1.8	4	0.4	0.535	0.710
4. Unexplained variation	0.2	791	0.0003			656.0	791	0.8		
5. Total variation	0.3	800				715.8	800			
SM										
1. Variation between sexes	134.7	1	134.7	4.130	0.042	5.2	1	5.2	5.353	0.021
2. Variation between habitats	924.5	4	231.1	7.089	0.000	20.4	4	5.1	5.192	0.000
3. Interactions	269.8	4	67.4	2.068	0.083	2.5	4	0.6	0.629	0.642
4. Unexplained variation	25790.0	791	32.1			775.5	791	1.0		
5. Total variation	27244.3	800				804.3	800			
BM										
1. Variation between sexes	168.5	1	168.5	11.336	0.001	15.529	1	15.5	16.364	0.000
2. Variation between habitats	714.6	4	178.6	12.019	0.000	20.862	4	5.2	5.496	0.000
3. Interactions	56.2	4	14.0	0.945	0.437	5.272	4	1.3	1.389	0.236
4. Unexplained variation	11757.0	791	14.9			750.598	791	0.9		
5. Total variation	12752.7	800				791.927	800			
Shell size										
1. Variation between sexes						0.04	1	0.04	0.076	0.784
2. Variation between habitats						58.022	4	14.5	26.784	0.000
3. Interactions						0.585	4	0.1	0.270	0.897
4. Unexplained variation						397.508	734	0.5		
5. Total variation						457.608	743			
Shell shape										
1. Variation between sexes						0.003	1	0.003	0.003	0.958
2. Variation between habitats						21.614	4	5.4	5.524	0.000
3. Interactions						4.798	4	1.2	1.226	0.298
4. Unexplained variation						717.954	734	1.0		
5. Total variation						745.482	743			

df – degrees of freedom, F – value of Snedecor function, p – probability of acceptance of null hypothesis

Table 22. Bi-variate analysis of metric characters (ANOVA II) in *Unio tumidus* for sex and type of habitat

Source of variation	Non-standardised data					Age-standardised data				
	Sum of squares	df	Mean square	F	p	Sum of squares	df	Mean square	F	p
L										
1. Variation between sexes	242.4	1	242.4	1.801	0.180	0.2	1	0.2	0.319	0.572
2. Variation between habitats	6739.7	3	2246.6	16.695	0.000	70.2	3	23.4	31.102	0.000
3. Interactions	345.6	3	115.2	0.856	0.464	3.3	3	1.1	1.450	0.228
4. Unexplained variation	47905.9	356	134.6			267.8	356	0.8		
5. Total variation	55949.3	363				349.4	363			
H										
1. Variation between sexes	64.7	1	64.7	2.136	0.145	0.5	1	0.5	0.633	0.427
2. Variation between habitats	1456.8	3	485.6	16.044	0.000	63.4	3	21.1	26.979	0.000
3. Interactions	124.3	3	41.4	1.369	0.252	3.9	3	1.3	1.637	0.180
4. Unexplained variation	10774.9	356	30.3			278.7	356	0.8		
5. Total variation	12500.0	363				352.2	363			
L/H										
1. Variation between sexes	0.00003	1	0.00003	0.047	0.828	0.1	1	0.1	0.137	0.711
2. Variation between habitats	0.01	3	0.003	6.060	0.000	19.1	3	6.4	8.958	0.000
3. Interactions	0.003	3	0.0009	1.684	0.170	2.3	3	0.8	1.095	0.351
4. Unexplained variation	0.2	356	0.0005			252.7	356	0.7		
5. Total variation	0.2	363				274.8	363			
C										
1. Variation between sexes	48.8	1	48.8	3.462	0.064	1.7	1	1.7	1.899	0.169
2. Variation between habitats	422.9	3	141.0	9.997	0.000	32.2	3	10.7	11.655	0.000
3. Interactions	43.91	3	14.6	1.038	0.376	8.6	3	2.9	3.096	0.027
4. Unexplained variation	5020.5	356	14.1			327.8	356	0.9		
5. Total variation	5576.6	363				377.8	363			
C/L										
1. Variation between sexes	0.0004	1	0.0004	0.782	0.377	0.8	1	0.8	1.304	0.254
2. Variation between habitats	0.03	3	0.009	16.816	0.000	33.1	3	11.0	18.370	0.000
3. Interactions	0.005	3	0.002	3.444	0.017	5.9	3	2.0	3.273	0.021
4. Unexplained variation	0.2	356	0.0005			214.0	356	0.6		
5. Total variation	0.2	363				261.5	363			
SM										
1. Variation between sexes	67.7	1	67.7	0.938	0.334	0.2	1	0.2	0.223	0.637
2. Variation between habitats	2517.7	3	839.2	11.624	0.000	58.0	3	19.3	20.258	0.000
3. Interactions	99.2	3	33.1	0.458	0.712	5.4	3	1.8	1.887	0.131
4. Unexplained variation	25702.5	356	72.2			339.5	356	1.0		
5. Total variation	28598.2	363				409.6	363			
BM										
1. Variation between sexes	17.1	1	17.1	0.981	0.323	0.1	1	0.1	0.136	0.713
2. Variation between habitats	1417.9	3	472.6	27.157	0.000	112.2	3	37.4	44.571	0.000
3. Interactions	33.4	3	11.1	0.639	0.590	2.6	3	0.9	1.043	0.374
4. Unexplained variation	6195.7	356	17.4			298.7	356	0.8		
5. Total variation	7825.7	363				428.5	363			
Shell size										
1. Variation between sexes						3.5	1	3.5	5.210	0.023
2. Variation between habitats						5.6	3	1.9	2.762	0.042
3. Interactions						2.9	3	1.0	1.419	0.237
4. Unexplained variation						217.1	319	0.7		
5. Total variation						228.3	326			
Shell shape										
1. Variation between sexes						0.03	1	0.03	0.018	0.892
2. Variation between habitats						201.2	3	67.1	39.721	0.000
3. Interactions						0.08	3	0.03	0.015	0.997
4. Unexplained variation						538.5	319	1.7		
5. Total variation						744.0	326			

df – degrees of freedom, F – value of Snedecor function, p – probability of acceptance of null hypothesis

Table 23. Bi-variate analysis (ANOVA II) of metric characters in *Anodonta anatina* for sex and types of aquatic habitats

Source of variation	Non-standarised data					Age-standarised data				
	Sum of squares	df	Mean square	F	p	Sum of squares	df	Mean square	F	p
L										
1. Variation between sexes	2387.6	1	2387.6	13.888	0.000	10.6	1	10.6	14.473	0.000
2. Variation between habitats	10974.1	3	3658.0	21.278	0.000	53.5	3	17.8	24.317	0.000
3. Interactions	935.8	3	311.9	1.815	0.144	2.5	3	0.8	1.149	0.329
4. Unexplained variation	60171.9	350	171.9			256.7	350	0.7		
5. Total variation	77045.9	357				328.6	357			
H										
1. Variation between sexes	446.3	1	446.3	9.903	0.002	6.8	1	6.8	9.635	0.002
2. Variation between habitats	2942.4	3	980.8	21.763	0.000	70.3	3	23.4	33.263	0.000
3. Interactions	364.8	3	121.6	2.698	0.046	4.6	3	1.5	2.194	0.089
4. Unexplained variation	15773.6	350	45.1			246.5	350	0.7		
5. Total variation	20028.0	357				331.9	357			
H/L										
1. Variation between sexes	0.003	1	0.003	3.011	0.084	1.7	1	1.7	2.418	0.121
2. Variation between habitats	0.1	3	0.04	42.797	0.000	75.9	3	25.3	36.665	0.000
3. Interactions	0.002	3	0.001	0.781	0.505	2.6	3	0.9	1.263	0.287
4. Unexplained variation	0.4	350	0.001			241.4	350	0.7		
5. Total variation	0.5	357				331.4	357			
C										
1. Variation between sexes	631.4	1	631.4	23.552	0.000	18.1	1	18.1	26.386	0.000
2. Variation between habitats	2424.7	3	808.2	30.149	0.000	80.0	3	26.7	39.094	0.000
3. Interactions	102.5	3	34.2	1.274	0.283	3.5	3	1.2	1.717	0.163
4. Unexplained variation	9382.8	350	26.8			238.8	350	0.7		
5. Total variation	12970.2	357				345.7	357			
C/L										
1. Variation between sexes	0.0	1	0.02	16.888	0.000	12.0	1	12.0	16.572	0.000
2. Variation between habitats	0.1	3	0.02	20.673	0.000	54.4	3	18.1	25.017	0.000
3. Interactions	0.0	3	0.001	1.243	0.294	3.7	3	1.2	1.697	0.167
4. Unexplained variation	0.4	350	0.001			253.9	350	0.7		
5. Total variation	0.5	357				325.6	357			
SM										
1. Variation between sexes	126.5	1	126.5	2.391	0.123	3.4	1	3.4	3.910	0.049
2. Variation between habitats	2953.1	3	984.4	18.603	0.000	65.7	3	21.9	25.346	0.000
3. Interactions	95.1	3	31.7	0.599	0.616	2.8	3	0.9	1.097	0.351
4. Unexplained variation	18520.4	350	52.9			302.6	350	0.9		
5. Total variation	22096.6	357				378.9	357			
BM										
1. Variation between sexes	21.9	1	21.9	28.488	0.000	1338.2	1	1338.2	15.028	0.000
2. Variation between habitats	97.8	3	32.6	42.353	0.000	6591.0	3	2197.0	24.673	0.000
3. Interactions	3.1	3	1.0	1.363	0.254	65.2	3	21.7	0.244	0.865
4. Unexplained variation	269.4	350	0.8			31165.6	350	89.0		
5. Total variation	397.5	357				39933.6	357			
SHELL SIZE										
1. Variation between sexes						0.3	1	0.3	0.154	0.695
2. Variation between habitats						69.6	3	23.2	11.497	0.000
3. Interactions						2.4	3	0.8	0.397	0.756
4. Unexplained variation						627.1	311	2.0		
5. Total variability						701.6	318			
SHELL SHAPE										
1. Variation between sexes						0.1	1	0.08	0.085	0.771
2. Variation between habitats						14.4	3	4.8	4.892	0.002
3. Interactions						2.7	3	0.9	0.903	0.440
4. Unexplained variation						304.6	311	1.0		
5. Total variability						323.0	318			

df – degrees of freedom, F – value of Snedecor function, p – probability of acceptance of null hypothesis

Table 24. Bi-variate analysis of metric characters (ANOVA II) in *Anodonta cygnea* f. *cellensis* for sex and type of habitat

Source of variation	Non-standardised data					Age-standardised data				
	Sum of squares	df	Mean square	F	p	Sum of squares	df	Mean square	F	p
L										
1. Variation between sexes	1767.6	1	1767.6	2.423	0.121	0.03	1	0.03	0.039	0.844
2. Variation between habitats	9208.3	1	9208.3	12.621	0.000	18.8	1	18.8	21.888	0.000
3. Interactions	66.0	1	66.0	0.090	0.764	0.2	1	0.2	0.175	0.676
4. Unexplained variation	143727.3	197	729.6			168.8	197	0.9		
5. Total variation	156323.12	200				188.0	200			
H										
1. Variation between sexes	358.6	1	358.6	2.403	0.123	0.2	1	0.2	0.215	0.644
2. Variation between habitats	1529.2	1	1529.2	10.247	0.002	16.0	1	16.0	14.701	0.000
3. Interactions	62.1	1	62.1	0.416	0.520	0.05	1	0.05	0.050	0.824
4. Unexplained variation	29399.3	197	149.2			214.3	197	1.1		
5. Total variation	31404.2	200				230.7	200			
H/L										
1. Variation between sexes	0.0002	1	0.0002	0.266	0.607	5.1	1	5.1	5.723	0.018
2. Variation between habitats	0.009	1	0.009	9.488	0.002	10.2	1	10.2	11.445	0.001
3. Interactions	0.001	1	0.002	2.132	0.146	10.4	1	10.4	11.698	0.001
4. Unexplained variation	0.18	197	0.001			175.2	197	0.9		
5. Total variation	0.19	200				197.1	200			
C										
1. Variation between sexes	439.0	1	439.0	4.552	0.034	0.02	1	0.02	0.023	0.879
2. Variation between habitats	1666.0	1	1666.0	17.271	0.000	24.5	1	24.5	24.216	0.000
3. Interactions	35.1	1	35.1	0.363	0.547	0.02	1	0.02	0.025	0.876
4. Unexplained variation	18999.5	197	96.4			199.0	197	1.0		
5. Total variation	21384.8	200				224.0	200			
C/L										
1. Variation between sexes	0.01	1	0.01	10.767	0.001	3.4	1	3.4	4.103	0.044
2. Variation between habitats	0.03	1	0.03	25.834	0.000	19.3	1	19.3	25.583	0.000
3. Interactions	0.005	1	0.005	4.751	0.030	1.8	1	1.8	2.209	0.139
4. Unexplained variation	0.20	197	0.001			161.5	197	0.8		
5. Total variation	0.23	200				183.9	200			
SM										
1. Variation between sexes	249.0	1	249.0	1.969	0.162	0.2	1	0.2	0.204	0.652
2. Variation between habitats	1487.1	1	1487.1	11.760	0.001	19.1	1	19.1	17.795	0.000
3. Interactions	2.8	1	2.8	0.022	0.882	0.1	1	0.1	0.108	0.743
4. Unexplained variation	24910.53	197	126.4			211.0	197	1.1		
5. Total variation	26950.9	200				230.5	200			
BM										
1. Variation between sexes	1116.8	1	1116.8	2.827	0.094					
2. Variation between habitats	5167.7	1	5167.7	13.083	0.000					
3. Interactions	25.6	1	25.6	0.065	0.799					
4. Unexplained variation	77813.6	197	395.0							
5. Total variation	86653.5	200								

df – degrees of freedom, F – value of Snedecor function, p – probability of acceptance of null hypothesis

Table 25. Differences in mean values of metric characters of *Unio pictorum* from different habitats (insignificant values underlined with continuous line)

Character		Non-standardised data					Test	Standardised data					Test
	a	2	3	4	5	1		5	1	4	3	2	
L (mm)	b	59.2	63.9	64.6	65.4	65.8	D	0.04	0.05	0.25	0.26	0.34	T
	c	223	123	86	248	121		248	121	86	123	223	
	a	2	4	3	1	5		1	5	2	4	3	
H (mm)	b	25.2	28.0	28.0	27.7	28.2	D	0.06	0.08	0.22	0.24	0.31	T
	c	223	86	123	121	248		121	248	223	86	123	
	a	2	4	1	3	5		2	4	1	3	5	
H/L	b	0.42	0.44	0.44	0.44	0.44	T	–0.51	–0.14	0.01	0.07	0.12	T
	c	223	86	121	123	248		223	86	121	123	248	
	a	2	4	3	1	5		1	5	4	2	3	
C (mm)	b	17.7	19.40	19.68	20.00	20.27	D	0.02	0.13	0.17	0.22	0.32	T
	c	223	86	123	121	248		121	248	86	223	123	
	a	2	4	1	3	5		2	4	1	3	5	
C/L	b	0.30	0.30	0.30	0.31	0.31	T	–0.42	–0.29	–0.13	0.09	0.09	T
	c	223	86	121	123	248		223	86	121	123	248	
	a	2	4	3	5	1		5	4	1	3	2	
SM (g)	b	8.71	9.53	10.50	11.13	11.39	D	–0.04	0.03	0.04	0.22	0.34	D
	c	223	86	123	248	121		248	86	121	123	223	
	a	2	5	4	3	1		5	1	2	4	3	
BM (g)	b	5.91	7.66	8.00	8.02	8.53	D	–0.10	0.09	0.15	0.32	0.35	D
	c	223	248	86	123	121		248	121	223	86	123	
	a							5	3	4	2	1	
SHELL SIZE	b							–0.41	–0.32	–0.30	0.01	0.40	D
	c							191	123	86	223	121	
	a							3	1	2	4	5	
SHELL SHAPE	b							–0.14	–0.10	0.05	0.27	0.30	D
	c							123	121	223	86	191	

Table 26. Differences in mean values of metric characters of *Unio tumidus* from different habitats (insignificant values underlined with continuous line)

Character		Non-standardised data				Test	Standardised data				Test
	a	5	4	3	1		5	3	4	1	
L (mm)	b	60.47	61.40	65.84	70.49	T	–0.42	–0.13	0.25	0.65	T
	c	98	49	41	176		98	41	49	176	
	a	5	4	3	1		5	3	4	1	
H (mm)	b	29.89	30.2	33.2	34.39	T	–0.42	0.05	0.20	0.61	T
	c	98	49	41	176		98	41	49	176	
	a	1	4	5	3		1	4	5	3	
H/L	b	0.49	0.49	0.50	0.505	T	–0.25	–0.22	0.03	0.47	D
	c	176	49	98	41		176	49	98	41	
	a	4	5	3	1		5	4	3	1	
C (mm)	b	20.34	20.84	22.84	22.97	T	–0.27	0.10	0.19	0.47	T
	c	49	98	41	176		98	49	41	176	
	a	1	4	3	5		1	4	5	3	
C/L	b	0.33	0.33	0.35	0.347	T	–0.42	–0.37	0.24	0.32	D
	c	176	49	41	98		176	49	98	41	
	a	4	5	3	1		5	4	3	1	
SM (g)	b	11.65	12.35	17.35	17.79	T	–0.42	–0.078	0.17	0.55	D
	c	49	98	41	176		98	49	41	176	
	a	5	4	3	1		5	3	4	1	
BM (g)	b	5.79	7.09	9.44	10.57	T	–0.65	0.18	0.22	0.76	T
	c	98	49	41	176		98	41	49	176	
	a						5	4	3	1	
SHELL SIZE	b						–0.37	–0.28	–0.27	1.28	D
	c						98	49	41	176	
	a						4	3	5	1	
SHELL SHAPE	b						–0.30	–0.24	–0.01	0.54	D
	c						49	41	98	176	

a – habitat: 1 – mid Pilica; 2 – lower Pilica; 3 – tributaries; 4 – oxbows; 5 – Sulejowski Reservoir; b – mean; c – number of specimens; D – Dunnett T_3 test; T – Tukey B test

Table 27. Differences in mean values of metric characters of *Anodonta anatina* from different habitats (insignificant values underlined with continuous line)

Character		Non-standardised data				Test	Standardised data				Test
L (mm)	a	5	3	1	2		5	1	3	2	
	b	61.70	73.88	77.53	78.89	T	–0.57	0.09	0.16	0.57	T
	c	62	58	86	152		62	86	58	152	
H (mm)	a	5	3	1	2		5	1	3	2	
	b	34.08	37.3	38.8	42.59	T	–0.33	–0.17	–0.08	0.72	T
	c	62	58	86	152		62	86	58	152	
H/L	a	1	3	2	5		3	1	2	5	
	b	0.50	0.51	0.54	0.55	T	–0.57	–0.55	0.33	0.60	D
	c	86	58	152	62		58	86	152	62	
C (mm)	a	5	3	1	2		5	1	3	2	
	b	17.34	22.50	23.30	25.28	D	–0.61	–0.01	0.15	0.69	T
	c	62	58	86	152		62	86	58	152	
C/L	a	5	1	3	2		5	1	3	2	
	b	0.28	0.30	0.30	0.32	D	–0.42	–0.13	0.11	0.54	D
	c	62	86	58	152		62	86	58	152	
SM (g)	a	5	3	1	2		5	1	3	2	
	b	4.83	10.54	12.46	13.26	D	–0.66	0.03	0.20	0.57	D
	c	62	58	86	152		62	86	58	152	
BM (g)	a	5	3	1	2		5	1	3	2	
	b	5.77	11.80	13.93	18.25	D	–0.68	–0.09	0.06	0.75	D
	c	62	58	86	152		62	86	58	152	
SHELL SIZE	a						5	3	2	1	
	b						–0.45	–0.36	0.39	0.94	D
	c						23	58	152	86	
SHELL SHAPE	a						3	1	2	5	
	b						–0.36	–0.01	0.00	0.61	D
	c						58	86	152	23	

a – habitat: 1 – mid Pilica; 2 – lower Pilica; 3 – tributaries; 4 – oxbows; 5 – Sulejowski Reservoir; b – mean; c – number of specimens; D – Dunnett T_3 test; T – Tukey B test

Table 28. Differences in mean values of metric characters of *Anodonta cygnea* from different habitats (insignificant values underlined with continuous line)

Character		Non-standardised data			Test	Standardised data			Test
L (mm)	a	5	4	1		5	1	4	
	b	69.64	97.01	103.06	D	–0.75	0.12	0.13	D
	c	32	301	58		24	52	178	
H (mm)	a	5	4	1		5	1	4	
	b	35.50	44.5	47.9	D	–0.63	0.12	0.17	D
	c	32	204	58		24	52	178	
H/L	a	1	4	5		1	4	5	
	b	0.46	0.49	0.51	T	–0.41	0.04	0.85	T
	c	58	204	32		52	178	24	
C (mm)	a	5	4	1		5	1	4	
	b	17.70	26.98	29.61	D	–0.86	–0.06	0.17	D
	c	32	204	58		24	52	178	
C/L	a	5	1	4		5	1	4	
	b	0.25	0.29	0.29	T	–0.84	0.33	147	T
	c	32	58	204		24	52	178	
SM (g)	a	5	4	1		5	4	1	
	b	5.92	13.70	20.90	D	–0.82	0.08	0.22	D
	c	32	204	58		24	178	52	
BM (g)	a	5	1	4		5	1	4	
	b	7.75	21.16	22.63	D	–0.76	–0.27	0.22	D
	c	32	58	204		24	52	178	
SHELL SIZE	a					5	4	1	
	b					–0.44	–0.29	–0.12	T
	c					23	301	58	
SHELL SHAPE	a					1	4	5	
	b					–0.53	0.00	0.28	T
	c					58	301	23	

a – habitat: 1 – mid Pilica; 2 – lower Pilica; 3 – tributaries; 4 – oxbows; 5 – Sulejowski Reservoir; b – mean; c – number of specimens; D – Dunnett T_3 test; T – Tukey B test

Table 29. Comparison of mean body mass (BM) and shell mass (SM) in five species of Unionidae

Species	N	mean shell mass (g) ± SD	mean body mass (g) ± SD	relation SM < – > BM
U. pictorum	801	10.23±5.83	7.40±3.99	SM > BM by 38%
U. tumidus	364	15.45±8.87	8.69±4.64	SM > BM by 43 %
U. crassus	56	16.40±8.00	8.88±3.61	SM > BM by 45%
A. anatina	358	9.03±7.68	14.00±10.57	BM > SM by 35%
A. cygnea f. *cellensis*	294	14.28±11.76	20.70±18.74	BM > SM by 31%

Table 30. Biomass of five species of Unionidae (wet body mass with shell) in gm^{-2} in various types of habitats (number of specimens in parentheses)

Type of habitat	*U. pictorum*	*U. tumidus*	*U. crassus*	*A. anatina*	*A. cygnea* f. *cellensis*	Total biomass
mid Pilica	582.42 (233)	2838.38 (371)	28.72 (20)	207.13 (128)	1065.88 (58)	4722.53
lower Pilica	75.61 (338)	–	–	76.66 (175)	–	184.47
oxbows	94.11 (94)	66.49 (55)	–	1.29 (6)	263.82 (298)	434.70
Sulejowski Reservoir	486.04 (406)	179.92 (246)	–	32.20 (131)	39.22 (32)	737.38

4.3.4. Biomass distribution

The highest mean biomass of unionids was noted in the mid section of the river. The total for all the species was 4,722.53 gm^{-2} (Table 30). The highest proportion was that of *U. tumidus* whose mean biomass was extremely high, amounting to 2,838.38 gm^{-2}. The highest biomass, at a single locality in that section of the Pilica, was recorded in Komorniki Bielskie (loc. 31a) and was 7,610.4 gm^{-2}. Considerably lower mean biomass values were noted in the remaining types of habitats. In the Sulejowski Reservoir the biomass was 737.38 gm^{-2}, in the oxbows 434.7 gm^{-2}, and the lowest values were found in the lower Pilica (184.47 gm^{-2}) (Table 30).

The mean biomass values for particular unionid species (shell mass and fresh body mass) were clearly different. The biomass of *U. tumidus* in the Sulejowski Reservoir was 15 times lower than that in the mid Pilica and amounted only to 179.92 gm^{-2}, the lowest biomass was observed in the oxbows (94.11 gm^{-2}) (Table 30).

The second highest biomass was that of *U. pictorum*. Like in *U. tumidus*, its maximum mean biomass, though much lower, was observed in the mid Pilica. It amounted to 582.42 gm^{-2}. The highest value was noted in Przewóz (loc. 30) where the biomass reached 1,438 gm^{-2}, it was lower in the Sulejowski Reservoir (486.04 gm^{-2}), the lowest values being those in the lower Pilica (75.61 gm^{-2}) (Table 30). The high biomass of *U. pictorum* in the mid Pilica was affected by both high shell mass values (11.39±5.77 g) and body mass values (8.53±3.85 g) (Table 15).

Like both species of the genus *Unio*, *A. cygnea* reached its highest mean biomass in the mid section of the Pilica (1,065.88 gm^{-2}, at a density of 2.9±2.53 Nm^{-2}) (Table 5). The bivalve formed a dense aggregation in Kurnędz (loc. 38b), of the highest density in the study area (28 Nm^{-2}) and the highest biomass (1,177.9 gm^{-2}). Much lower biomass values were noted in the oxbows, where the mean value was 263.82 gm^{-2}. Locally (loc. 66) the biomass reached 814.4 gm^{-2} (density 16 Nm^{-2}). The lowest mean biomass of the species (39.22 gm^{-2}) (Table 30) was found in the Sulejowski Reservoir.

The mean biomass of *A. anatina* was among the lowest in the Pilica catchment area. In the mid Pilica the mean was 207.13 gm^{-2}. The maximum value was noted in Przewóz (loc. 30), and it amounted to 398.8 gm^{-2}, and in the Sulejowski Reservoir the value was only 32.30 gm^{-2} (Table 30). Low biomass values were observed also for *U. crassus*, the value in the mid Pilica being only 28.72 gm^{-2} (Table 30).

The mean biomass of *P. complanata* in the mid Pilica was 53.95 gm^{-2} (Table 30). Because of the scarcity of material the biomass in stagnant reservoirs and tributaries was not calculated.

4.4. INTERACTIONS BETWEEN THE UNIONIDS AND THE ZEBRA MUSSEL

During the 1997 studies on the distribution of unionids in the Sulejowski Reservoir, I observed a mass appearance of *Dreissena polymorpha*, and in 1998 the phenomenon was noted also in the lower section of the Pilica (ABRASZEWSKA-KOWALCZYK et al. 1999). The zebra mussels inhabiting the Sulejowski Reservoir grouped mainly in the region of the dam, where they covered hydrotechnical equipment in masses. In the littoral zone of the reservoir – because of the

Table 31. Square and linear regression – effect of zebra mussel aggregations on unionid condition

	df	b	β	t°	p		df	b	β	t°	p
Unio pictorum											
R^2 = 0.77760		no zebra mussels on shells				R^2 = 0.82919		with zebra mussels on shells			
height (H)	878	0.882	0.891	56.782	0.0000	height (H)	101	0.633	0.910	21.912	0.0000
height**2		0.063	0.093	5.927	0.0000	height**2					0.8618
Unio tumidus											
R^2 = 0.75629		no zebra mussels on shells				R^2 = 0.83641		no zebra mussels on shells			
height (H)	523	0.858	0.830	38.391	0.0000	height (H)	25	0.845	1.175	9.246	0.0000
height**2		0.179	0.256	11.841	0.0000	height**2		0.114	0.401	3.155	0.0044
Anodonta anatina											
R^2 = 0.69657		no zebra mussels on shells				R^2 = 0.74893		no zebra mussels on shells			
height (H)	389	0.854	0.801	28.584	0.0000	height (H)	68	0.825	0.827	13.029	0.0000
height**2		0.168	0.209	7.444	0.0000	height**2		0.078	0.122	1.923	0.0589

b – regression coefficient, t° – value of t-Student function, p – statistical significance, df – degrees of freedom

sandy or muddy bottom deposits and the absence of vegetation – the mussels used mainly shells of live and dead unionids and submerged objects as a substratum. In 1997 over 50% unionids collected in the reservoir were covered by aggregations of the zebra mussel. Observations made in subsequent years indicate an increasing percentage of mussel-covered unionids. In 1998, in the lower section of the Pilica over 90% unionid shells were covered by *D. polymorpha* (ABRASZEWSKA-KOWALCZYK et al. 1999).

The condition of unionids in the Sulejowski Reservoir was estimated based on square and linear regression. The dependence between the shell height and body mass was analysed in the mussel-devoid and mussel-covered unionids. The results are presented in Table 31.

In the case of specimens of *U. pictorum* which were not covered by the mussels the regression was curvilinear and described by the equation y=0.007+0.882x +0.063x²+e (Fig. 30a). The dependence is an allometric function (LAMPERT & SOMMER 1996) and im-

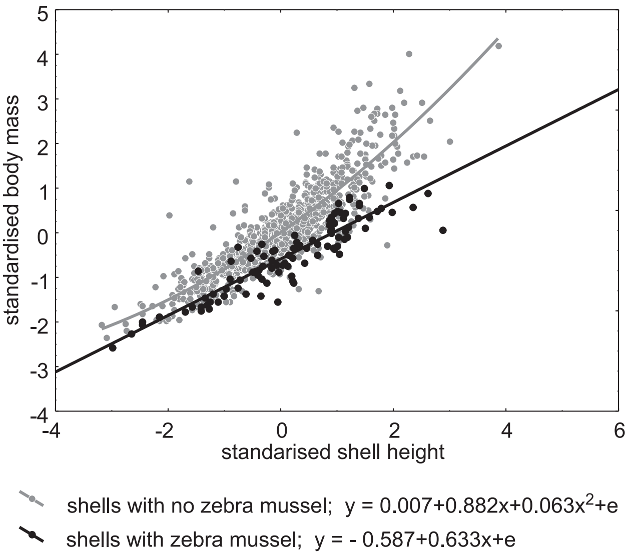

Fig. 30a. Condition of *Unio pictorum*

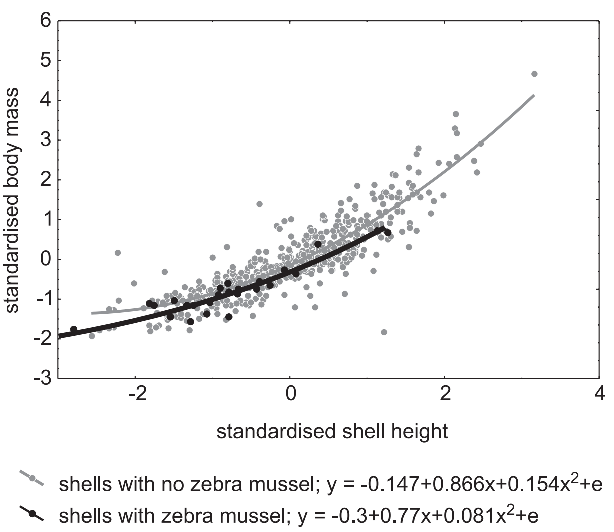

Fig. 30b. Condition of *Unio tumidus*

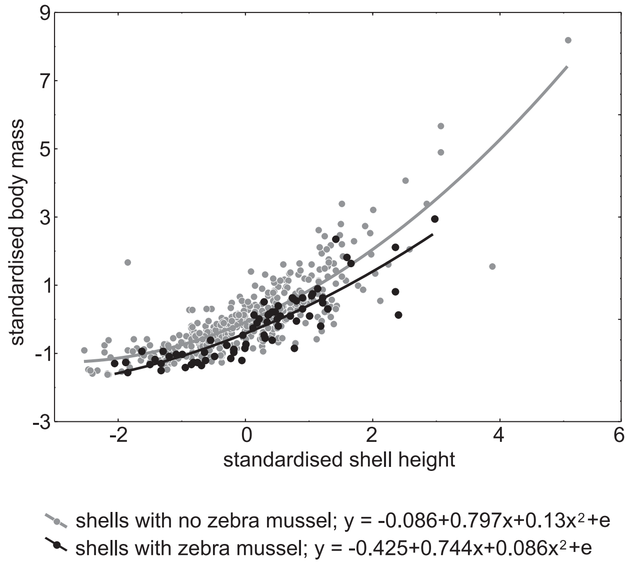

Fig. 30c. Condition of *Anodonta anatina*

plies that the body mass increases faster than the linear parameter.

The regression for mussel-covered *U. pictorum* was rectilinear, and described by the equation $y = -0.587+0.633x+e$ (Fig. 30a). The rectilinear character of the regression shows a poorer condition of bivalves with mussels on their shells: at the same shell height the unionids with mussels on their shells had a lower body mass.

In the case of *U. tumidus* (Table 31) both regressions (for unionids with and without the mussels) were curvilinear (Fig. 30b). However, a comparison of b_2 coefficient with Student t-test between the curves indicates significant differences in their bent and course ($t^o=1.65$, $p=0.05$, H_A one-sided) which confirms a poorer condition of individuals with mussels on their shells. Mussel-bearing specimens are smaller and their regression is closer to rectilinear. *U. tumidus* with no mussels on their shells are larger and body mass increases faster than the linear parameter.

A similar course of regression lines was found also for *A. anatina* (Table 31). Though both regressions are curvilinear (Fig. 30c), a comparison of b_2 coefficient indicates a significant difference in the bent of the curve between the mussel-bearing and mussel-free unionids ($t^o=1.93$, $p<0.05$, H_A one-sided) which indicates that the mussel-bearing individuals are smaller, and their regression is closer to rectilinear – the body mass increases slower compared to the increase in the body mass of the mussel-free bivalves.

DISCUSSION

The unionid fauna of the Pilica catchment area includes all the members of *Unio* Philippson and *Anodonta* Lamarck known to occur in Poland (PIECHOCKI & DYDUCH-FALNIOWSKA 1993). Like in other rivers of Poland, *U. pictorum, U. tumidus* and *A. anatina* are common, while rare forms include *P. complanata* and *A. cygnea*. There is, however, a significant difference in the distribution and abundance of *U. crassus*. The species was often recorded from most rivers where it constituted a constant component of unionid beds (MENTZEN 1925, PIECHOCKI 1969a, LEWANDOWSKI 1990).

The observed scarcity of *U. crassus* in the Pilica and its tributaries is probably the effect of progressing eutrophication of the river, as recently pointed out by PIECHOCKI (1999). HOCHWALD & BAUER (1990) report that increased content of nitrates in the water clearly limits the development of young individuals of the species. Also in other rivers of the region of Łódź, among others the Grabia, Widawka and Warta, a rapid extinction of *U. crassus* was observed in recent years, probably associated with excessive fertilisation of cultivated fields (surface flux of nitrates), buildings constructed on the river banks (summer bungalows) and effect of communal sewage. On the other hand, in pure rivers, especially in northern and eastern Poland – the Rospuda, mid Narew, Brda, Czarna Woda – there still exist abundant populations of *U. crassus* which is due to a relatively low anthropopressure (unpublished observations by ABRASZEWSKA-KOWALCZYK and PIECHOCKI of 1992–1999).

The presence of *A. cygnea*, classified as rare and not abundant (cd), in the study area is also noteworthy. In the context of the opinion expressed by PIECHOCKI & DYDUCH-FALNIOWSKA (1993) – "in Poland the species is very rare" – the population from the Pilica seems to be fairly abundant and not threatened with extinction. Favourable conditions for the species are provided by numerous oxbows, well preserved especially along the mid course of the river. In the river a locality with abundant occurrence of *A. cygnea* was found in Kurnędz (loc. 38b), where there was an aggregation of *A. cygnea* f. *cygnea* of a density of 28 Nm^{-2}. The species occurs also in other European rivers where it reaches similar densities (BLESS 1981, LEWANDOWSKI 1990).

The distribution of *P. complanata* in the study area does not depart from that observed in other regions of Poland (e.g. POLIŃSKI 1917, URBAŃSKI 1933, 1938, LEWANDOWSKI 1990, 1991). Everywhere the bivalve was rare and not abundant, preferring flowing waters. It seems that also this species – in spite of its rather low abundance – is not threatened with extinction in the Pilica catchment area.

In the literature there are only few papers dealing with the distribution of unionids along rivers or streams of Poland. LEWANDOWSKI (1990) found that in the Szeszupa unionids appeared only in the "mature" river 3–4 m wide, while the upper, stream section was completely devoid of them. The first species to appear were *A. piscinalis* (=*A. anatina*) and *U. crassus*, then – with the development of the river – they were joined by *P. complanata, A. cygnea, U. pictorum* and *U. tumidus*.

In the Grabia River the earliest to appear was *A. anatina* (uppermost section in Grabica), then in the upper section the fauna was enriched with *U. pictorum* (Mzurki), *U. tumidus* (Drużbice), *A. cygnea* (Pawłowa) and *U. crassus* (Kuźnica), and then – in the lower section (from the settlement of Brzeski) – there occurred *P. complanata* (PIECHOCKI 1969a). According to the observations by MENTZEN (1925, 1926) in submontane streams of Lower Silesia the species living closest to the sources is *U. crassus* while only the lower sections are inhabited by *U. pictorum, U. tumidus* and members of *Anodonta*.

The distribution of unionids in the Pilica is completely different. The upper section of the river (from the sources to the village Modła), ca. 80 km long, is devoid of unionids. They appear in Pukarzewo (loc. 13, 82nd km) where they are represented by one species only: *U. pictorum*. Somewhat lower (Mosty – 86th km and Maluszyn – 88th km) the river fauna is enriched with further four species: *U. crassus, U. tumidus, A. anatina* and *P. complanata*, which, together with *U. pictorum*, at a smaller or greater density occur along the whole mid section of the Pilica. *A. cygnea* f. *cellensis* appears in the village Placówka (loc. 29; 143rd km) and is sporadically found in lower situated river localities, whereas *A. cygnea* f. *cygnea* lives only in the lowermost section of the river.

The absence of unionids in the upper section of the Pilica may result from a variety of reasons. The most important of these seem to be heavy water pollution and regulation of the river bed. An additional factor may be also the lack of host fishes that could be parasitised by larval stages of unionids – glochidia. The latter problem, however, requires detailed studies since till now it remains unknown which fish species are hosts for glochidia in Poland.

The distribution of unionids along the Pilica is clearly disturbed by the dam reservoir. Below the dam, in the whole lower section of the river, the species composition of unionids is reduced to two unabundantly occurring species – *U. pictorum* and *A. anatina. A. cygnea* f. *cygnea,* found at one locality in the lowermost section, probably penetrated into the Pilica from the Vistula River. The impoverishment of the unionid fauna in river sections below dam reservoirs was observed also by other authors. TÓTH & BÁBA (1981) found a decrease in the number of species and decreasing abundance below a reservoir on the Tisza River. Likewise, MILLER et al. (1992) demonstrated, in the zone below the dam on the Tennessee River in the USA, a change in the species composition of unionids. It consisted in the disappearance of bivalves associated with fine-grained sandy or muddy deposits, disappearance of rare species and a radical decrease in the frequency of many other species, especially thin-shelled forms, e.g. *Anodonta grandis*. The observations of these authors indicate, however, a gradual recovery of the unionid fauna with increasing distance from the reservoir. The same process was observed in the lower Pilica.

The described phenomenon results probably from deposition of organic matter in the Sulejowski Reservoir. A slow-down or even complete inhibition of the water flow causes sestone particles carried by the waters of the Pilica to settle on the bottom, resulting in the river below the reservoir being devoid of a large proportion of fine detritus which is bivalve food. The resources of seston – allochthonous matter – in the lower Pilica are very slowly renewed which is associated with the absence of larger forest complexes in the immediate vicinity of the river. The results of analyses of the seston content in the Pilica indicate that this interpretation is correct in the case of *U. pictorum* and *U. tumidus*. The low number of analyses does not permit conclusions about such dependences for the remaining species.

The occurrence of unionids in the mid section of the Pilica is similar to that observed in some other European rivers, e.g. Schwalm in Hesse (NAGEL 1992), Tisza in Hungary (TÓTH & BÁBA 1981) or Paimionjoki in Finland (HAUKIOJA & HAKALA 1974).

The dominant species, typical of the mid section of the Pilica, is *U. tumidus*. Also in the Grabia (PIECHOCKI 1969a) and Szeszupa (LEWANDOWSKI 1990) the species was the most common, showing a continuous distribution in sections of a sandy-muddy bottom, abounding with allochthonous organic matter. Similar observations on the distribution of *U. tumidus* in the Tisza were reported by TÓTH & BÁBA (1981), who added that the species was also abundant in sandy sediments. In the Szeszupa *U. tumidus* formed large beds, of a density reaching 100–200 Nm^{-2} (LEWANDOWSKI 1990). In the mid Pilica the mean density was 67 Nm^{-2}, and in the beds it reached 250 Nm^{-2}. A much lower abundance of *U. tumidus* (0.6–2.0 Nm^{-2}), also in relation to other unionids, was found in the Thames (NEGUS 1966). BLESS (1981) reported a complete absence of *U. tumidus* in the recovering fauna of the Rhine.

The presented picture of the distribution of *U. tumidus* indicates that the species is euryoecious, of a high adaptive potential. It reaches the highest abundance in pure rivers of natural character, with a high content of organic matter in their bottom sediments, where it forms large beds. However, it is sensitive – according to ALLAN's (1998) terminology – to constant disturbances of the river system functioning.

U. pictorum, the second most common species in the Pilica, though less abundant, had a similar distribution in the Szeszupa (LEWANDOWSKI 1990). In the Grabia it was among the most frequent bivalves. It is a euryoecious species, of a considerable habitat tolerance (PIECHOCKI 1969) and according to TÓTH & BÁBA (1981) in the Tisza its highest density (88 Nm^{-2}) was observed in muddy sediments, while in sandy deposits the density was only 2.2 Nm^{-2}. In the Thames it was slightly more abundant than *U. tumidus*, its density ranging from 5.4 to 10.9 Nm^{-2} (NEGUS 1966). The species is resistant to anthropogenic changes in aquatic habitats; together with *A. anatina* it occurs in the lower section of the river, affected by the Sulejowski Reservoir, and as a pioneer species they appear in the purifying Rhine (BLESS 1981).

As was mentioned above, *A. anatina* is usually common in rivers, occurring along their whole course (LEWANDOWSKI & STAŃCZYKOWSKA 1995). In the Pilica, besides *U. pictorum*, it was noted in both the mid and the lower sections. In the mid Pilica it usually accompanied, though not abundantly, other unionids, in the lower section its occurrence was scattered. Its density in the studied sections of the Pilica (3.29 Nm^{-2}) was much lower than that in the Szeszupa (64 Nm^{-2}) (LEWANDOWSKI 1990), but it was only slightly different from the densities observed in the Thames (3.4–14.9 Nm^{-2}) or the Tisza (7 Nm^{-2}) (NEGUS 1966, TÓTH & BÁBA 1981).

Bottom sediments are among important habitat factors ensuring proper conditions for bivalves. The studies in the Pilica catchment area confirmed the observations of BRÖNMARK & MALMQVIST (1982) who analysed habitat preferences of *A. anatina* and *U. pictorum* in the Klingavalsan River flowing out of a lake. The species, though co-occurring, selected different microhabitats. Like observed in the Pilica, both species preferred sediments of medium grain size (0.125–0.5 mm) with a layer of silt. *U. pictorum*, which often embeds itself in the substratum, selected places with a larger admixture of silt, while *A. anatina* chose a more sandy bottom. Like in the Pilica, *U. pictorum* avoided macrophyte clumps, while *A. anatina* grouped in their vicinity. Both species avoided coarse-grained deposits which, according to the cited authors, make it difficult for them to move along the bottom. Besides the lack of seston, the absence of *U. pictorum* and *A. anatina* in the section of the Pilica just below the dam can be explained by the fact that corase-grained sediments dominate there. The results published by KAT (1982) demonstrated a considerable effect of the kind of sediment on the growth of bivalves, their density and possibility to move.

The unionid fauna of the Sulejowski Reservoir resembles that of the dam lake in Goczałkowice (KRZYŻANEK 1976, 1991, 1994). Its present species composition and dominance structure are to a large degree similar to those observed in the Goczałkowice Reservoir after 25 years of its existence. A characteristic feature of unionid assemblages was then the dominance of *U. pictorum*, a rather high abundance of *A. cygnea*, and a scarcity of *A. anatina* and *U. tumidus* (KRZYŻANEK 1994). The similarity between the faunas is manifest in the fact that also in the Sulejowski Reservoir there occur the above-mentioned species, the dominant being *U. pictorum*. A certain difference results mainly from the higher frequency and abundance of *U. tumidus*. Irrespective from the differences it seems that the structure of the unionid fauna and the long-term abundance dynamics are very similar in both these reservoirs. The reason for the similarities may be a similar character of the two dam lakes, with their strongly marked eutrophication processes.

Within the 30 years of existence of the Goczałkowice Reservoir a degradation of unionid population was observed, manifest among others as a drastic decrease in their abundance. According to KRZYŻANEK (1994) a mass bloom of blue-green algae *Gomphosphaeria naegeliana* and *Aphanizomenon flos-aquae* which took place in the Goczałkowice Reservoir in 1992, was the reason for the extinction of ca. 60% unionid population.

Though in the Sulejowski Reservoir no direct lethal effect of blue-green algal blooms on the unionid population was observed, and the experimental studies did not confirm the effect of blue-green algal toxins on bivalves (TARCZYŃSKA 2001), the results of the multivariate analysis showed that the condition of all species of unionids in the Sulejowski Reservoir (linear parameters of shell, age structure and biomass) was worse compared to the unionid condition in other habitats of the Pilica catchment area.

The reasons for this situation may be sought in the presence of high concentrations of biogenic substances, noted in the Sulejowski Reservoir for many years (Reports on the state of environment in the Łódź voivodeship in 1996, 1997, Piotrków voivodeship in 1997). Biogenic substances affect the development of phytoplankton and blue-green algae, which in turn is reflected by high concentrations of a chlorophyll and seston, and also periodically low concentrations of dissolved oxygen. My studies showed that both increased values of biogenic substances and chlorophyll a, and low oxygen concentrations (high level of BOD_5) could negatively affect the condition of unionids (contrary to high levels of suspension which may be tolerated by the bivalves). This, however, does not explain the effect of blue-green algal toxins on unionids. There is thus a need for further experimental studies in both natural and laboratory conditions. The duration of TARCZYŃSKA's (2001) experiment seems to be too short. This is associated with the physiology of unionids and the well known mechanism of shell opening described, among others, by KRAMER et al. (1989) and ENGLUND & HEINO (1994a, b). The unionids are extremely sensitive, closing their shells in stress situations, such as water temperature change or change of light, or pollution influx (ENGLUND et al. 1994).

One of the reasons for the poor condition of unionids in the Sulejowski Reservoir may be zebra mussels whose masses cover the unionid shells, and which compete with the unionids for food.

The qualitative and quantitative diversification of the unionid fauna in the floodplain water bodies observed in this study confirms the results of earlier studies by PIECHOCKI (1969a) and NAGEL (1987). The characteristic species is *A. cygnea*, while abundant and more or less common species include *U. pictorum* and *U. tumidus*. It should be stressed that unionids occur mainly close to connections between the oxbows and the Pilica.

The fauna of the tributaries was qualitatively and quantitatively poorer than in the Pilica. A relatively high abundance of *U. crassus* in some water courses is noteworthy; according to HOCHWALD & BAUER (1990) and HOCHWALD (1997) it indicates purity of water.

A more complete estimate of the unionid abundance in the Pilica catchment area resulted from both quantitative (1 m^2 area) and semi-quantitative ("time" sampling) methods. As observed by MILLER & PAYNE (1993), who studied populations of bivalves in the Ohio River, also in the Pilica the semi-quantitative samples made it possible to document the presence of rare species or species of low abundance. Thus, e.g. *U. crassus* which in quantitative samples was found only at four sites in the mid Pilica, in semi-quantitative samples was noted in seven sections of the river. Similar regularities apply to the number of collected specimens. In case of *A. anatina* semi-quantitative samples made it possible to classify it as a common species though its abundance was low.

The analysis of spatial distribution of unionids demonstrated that both in the Pilica and in the Sulejowski Reservoir and oxbows the bivalves occurred in aggregations, forming more or less compact beds. The phenomenon is usually interpreted as adaptation to reproduction of animals of external fertilisation and separate sexes, since at higher densities the eggs deposited in outer demibranchs of females have a greater chance to be fertilised (ZHADIN 1938, PIECHOCKI 1969b, BAUER 1987, 1994). It seems that an equally important reason for the clustered distribution is the filtratory mode of feeding and the associated necessity to select places where sedimentation of current-carried seston or particles suspended in stagnant water takes place. Observations on the Pilica populations revealed that such places in the river were located close to the banks, especially behind clumps of macrophytes and in bays or depressions situated close to the shore. As a result of the current slowing down, in such microhabitats there is an intense sedimentation of the suspended organic matter which the bivalves catch with their siphons. It should be stressed that the association of the unionid distribution with sedimentation of detritus and feeding was not previously noticed by malacologists or hydrobiologists.

In the Sulejowski Reservoir the unionids were also observed to accumulate in the littoral zone. This may result from the use of organic matter that gets to the reservoir from its immediate surroundings. It should be also stressed that in the mid part of the reservoir the bottom deposits are "loose" which makes it impossible for the bivalves to live close to their surface. Zonation of unionid distribution in dam reservoirs was also observed by other authors (GRZYBOWSKA 1965, KRZYŻANEK 1976, 1977, 1991, 1994, NAGEL 1987, JURKIEWICZ-KARNKOWSKA 1989).

As was already mentioned, also in the oxbows unionids showed a clustered distribution. Their highest density was observed where the oxbows were connected with the river and where – on the border between the stagnant and flowing water – organic particles settled. In the oxbows another decisive factor affecting bivalve distribution may be a better oxygenation of water coming from the river.

A uni-variate analysis showed an age differentiation in the populations of unionids living in various types of habitats. All the four species included in the analysis: *U. pictorum, U. tumidus, A. anatina* and *A. cellensis* reached their highest mean age in the mid Pilica which may be associated with the natural character of the river and food abundance.

The analysis of metric characters of particular species made it possible to find statistically significant differences in linear parameters of the shell, shell mass and body mass, between the bivalves from the mid Pilica, lower Pilica, tributaries, oxbows and the Sulejowski Reservoir which, combined with the data on the age structure, enables conclusions regarding their condition. The use of standardised measurements in the bi-variate analysis made it possible to eliminate the effect of age (through its stabilisation), facilitating the interpretation. The method makes it possible to avoid interpretation problems resulting from complex statistical analysis, encountered by other authors, e.g. CASTAGNOLO et al. (1977).

Metric characters of *U. tumidus* in the studied area differed statistically significantly between the types of habitats. The measurements (as exemplified by shell length) were characterised by a high inter-population variation. The differentiating effect of habitat factors on unionid populations was discussed earlier by TUDORANCEA (1968) and TIMM (1994).

The size of *U. tumidus* from the Pilica catchment area did not depart significantly from the measurements given in literature. The mean shell length of the bivalves from all the sites was 66.04±12.41 mm, being significantly higher in specimens from the mid Pilica, and the smallest in those from the Sulejowski Reservoir and the oxbows.

According to LEWANDOWSKI (1990) in the Szeszupa the mean length varied from 60 to 70 mm. In the lake complex Crapina-Jijila in the Danube delta the bivalves were 48–68 mm long (TUDORANCEA 1968, 1969, 1972), in lake Kortowskie their length ranged from 15 to 65 mm (WIDUTO & KOMPOWSKI 1968) while in Scandinavian lakes of various trophy the range was 57–74 mm (AGRELL 1949). The smallest mean length – 54.2 mm – was found in bivalves from the Goczałkowice Reservoir (KRZYŻANEK 1994). Their shell length was much smaller compared to specimens from the Sulejowski Reservoir (60.47±12.38). Exceptionally large shells, from 70 to 110 mm in length, were found in muddy deposits in a floodplain reservoir of the Fulda (NAGEL 1987). Compared to the bivalves from the Pilica catchment area, those from lake Crapina were much shorter and more tumid (TUDORANCEA 1968). The author explained the shortened shell outline by an adaptation to intense wave action and strong winds. The height/length ratio (H/L) and convexity index (C/L) reached high values in the unionids from the Sulejowski Reservoir. Like in lake Crapina, it may result from strong south-westerly winds, causing a strong wave action and changes in the shore line (GALICKA 1996).

The oldest observed age of *U. tumidus*, of over 11 years, was reported by NEGUS (1966) and TUDORANCEA (1968). A decrease in the maximum age of *U. tumidus* from 9 to 6 years resulting from a pollution of lake Mikołajskie was found by LEWANDOWSKI & STAŃCZYKOWSKA (1991). In the Pilica catchment area only the bivalves from the mid Pilica and tributaries reached the age of 9 years. In the Sulejowski Reservoir and in the lower section of the Pilica they lived only up to 6 years. Also the mean age of bivalves from the Sulejowski Reservoir and the oxbows was low, amounting to 3.3 years, while in the middle section of the river it reached 4.62 years.

Also in the case of *U. pictorum* the mean values of shell length varied between the habitats. In a pure Masurian river the dominant age class consisted of individuals 60–70 mm long (LEWANDOWSKI 1990). In the Goczałkowice Reservoir – at an early phase of its colonisation – the mean shell length was 74 mm and after 20 years decreased to 63 mm as a result of progressing eutrophication (KRZYŻANEK 1994). The bivalves inhabiting the floodplain reservoir on the Fulda were characterised by an unusually large size (length 55–95 mm) (NAGEL 1987).

The mean values of shell length of specimens from the Pilica catchment area (63.45±12.84 mm) are within the mean ranges of values reported in the literature. The lowest values of most metric characters of *U. pictorum* were observed in the lower Pilica. It was also there that the mean age of the bivalves was the lowest (3.01 years). The oldest individuals in the Pilica catchment area reached the age of 8 years. The maximum age reported in the literature is 10–13 years (NEGUS 1966, TUDORANCEA 1968, LEWANDOWSKI 1990). The highest mean age (4.72 years) was found for the bivalves from the mid Pilica, thus testifying to more favourable habitat conditions compared to the lower section of the river, where it was the lowest and amounted to 3.01 years.

European populations of *A. anatina* are characterised by a wide variation of metric shell characters. Hence an array of publications on the population structure of the species. Papers of such authors as ÖKLAND (1963), TUDORANCEA & FLORESCU (1969), BURLA (1971, 1972), BURLA et al. (1974) or HAUKIOJA & HAKALA (1978a, b, 1979) can be mentioned.

The population from the Pilica catchment area was characterised by a clear variation in metric characters. The mean shell length of *A. anatina* in the whole study area was 74.78±14.69 mm. The highest means were those of the bivalves from the lower Pilica. Also the maximum size (up to 112 mm in length) was significantly larger than the length of individuals from the Sulejowski Reservoir (the smallest in the study area). The size of bivalves from populations studied by other authors was similar. Thus e.g. in the Szeszupa it was 60–90 mm (LEWANDOWSKI 1990), in the Goczałkowice Reservoir 69 mm (1972) and 78 mm (1992) (KRZYŻANEK 1994), in a Swedish lake Borrevan 70–80 mm (ÖKLAND 1963).

In favourable conditions *A. anatina* may reach the age of 10–12 years (NEGUS 1966, TUDORANCEA 1968, TUDORANCEA & FLORESCU 1969). In case of increased water pollution the age of the bivalves undergoes a rapid decrease, examples being unfavourable changes in the age structure observed in lake Mikołajskie (LEWANDOWSKI 1991). The oldest individuals found there were only 7 years old. The mean age attained by *A. anatina* in the Pilica catchment area was low and amounted to 3.78 years. The lowest values of age (1.5 year) were noted in populations from the oxbows and the Sulejowski Reservoir. This is incompatible with NAGEL's(1987) opinion that *A. anatina* finds optimum growth conditions in stagnant waters.

Individuals of *A. cygnea* from the Pilica populations did not reach size reported by some authors (FELIKSIAK 1930, ZHADIN 1938). The low number of collected specimens of *P. complanata* and *U. crassus* does not allow a reliable morphometric estimate of these species.

The phenomenon of using shells of live unionids by the zebra mussels as substratum is commonly known. In lake Kortowskie over 40% unionid population had aggregations of zebra mussels attached to their shells (WIDUTO & KOMPOWSKI 1968) while in lake Miedwie the proportion reached 70% (ŚWIERCZYŃSKI 1997). The studies in the Sulejowski Reservoir in 1997 showed that over 50% unionids were covered by zebra mussels. In 1998 in the lower Pilica as much as 90% unionid population had zebra mussels on their shells. Some authors (LEWANDOWSKI 1976) found no negative effect of zebra mussel aggregations on unionids. The lack of negative effect could be, however, associated with the low numbers of zebra mussels on the unionid shells.

There exists a competition between unionids and *Dreissena polymorpha* (RICCIARDI et al. 1998). Observations of MACKIE (1993) demonstrate that mass covering by zebra mussels renders it difficult or even impossible for unionids to close their shells. This in turn precludes reactions to adverse environment changes and causes disturbance of respiration, feeding, reproduction or growth. The cited author observed also a negative effect of zebra mussels on the mobility and a limitation of feeding efficiency of unionids. He demonstrated a statistically significant dependence showing that *D. polymorpha* preferred unionid shells as substratum to other components of the bottom. A high negative correlation between the density of *D. polymorpha* and that of unionids was found by HUNTER & BAILEY (1992) in lake St. Clair in N America.

The studies on the effect of zebra mussels on the condition of unionids in the Sulejowski Reservoir confirmed the opinion on the negative effect of *D. polymorpha*. Regression analysis (ALIMOV 1974, ALIMOV & GOLIKOV 1974) for three common unionid species showed that the body mass increment in individuals with zebra mussels on their shells was smaller than the increment of the linear parameter (shell height). This indicates indirectly that the energy that should be expended for body mass increase was invested into counteracting negative effects of the presence of the mussels.

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