Arch. Pol. Fish.	Archives of Polish Fisheries	Vol. 15	Fasc. 4	369-385	2007

DEVELOPMENT OF THE ZEBRA MUSSEL, *DREISSENA POLYMORPHA* (PALL.), POPULATION IN A HEATED LAKES ECOSYSTEM. I. CHANGES IN POPULATION STRUCTURE

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ABSTRACT. The aim of the study was to describe the zebra mussel, *Dreissena polymorpha* (Pall.), population in the Konin heated lakes system during the 1993-2006 period. The impact of the effective temperature sum on the development of the population varied widely in the different habitats of this ecosystem within the range of 3720 to 7600 degree days and vegetation time period of 188 to 345 days, depending on the population's proximity to the heated water discharge from the power plant. The population occurring in the warmest zone of the system was of a simple structure with few age classes, a lower maximum individual weight, and an unbalanced sex ratio. The occurrence of zebra mussels in these habitats was negatively correlated with water temperature. The abundance of *D. polymorpha* in the zone with moderate heating was positively correlated with the effective temperature sum.

Key words: *DREISSENA POLYMORPHA,* ZEBRA MUSSEL, POPULATION STRUCTURE, DENSITY, BIOMASS, HEATED WATERS

INTRODUCTION

Zebra mussels, *Dreissena polymorpha* (Pall.), are an important element of aquatic ecosystems. When they occur at high density, they increases the intensity of the biological purification of waters. They facilitate the occurrence of other species thus contributing to increased biological diversity in biotic assemblages of zoobenthos and zooperiphyton. When populations of this mussel settle on underwater engineered structures, they can disrupt the functioning of cooling systems. The planktonic form of its larval stage and its tolerance to changing environmental conditions allows this species to expand its area of occurrence rapidly (Morton 1997).

The zebra mussel was first noted in western and central European waters in the eighteenth century and then again at the end of the nineteenth and the early twentieth

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centuries (De Vaate 1991, Stańczykowska 1997, Lewandowski 2001). The massive expansion of this species in the 1925–1950 period and the arrest of population development in the 1975–1990 period as a result of water eutrophication were generally both influenced by anthropogenic factors (Piechocki and Dyduch-Falniowska 1993, Lewandowski et al. 1997, Lewandowski 2001).

An extreme example of the impact environmental changes can have on the development of zebra mussel populations is in the heated Konin lakes located in the Wielkopolsko-Kujawskie Lakeland (central Poland), which have substantially heterogeneous thermal, hydrodynamic, and trophic conditions (Hillbricht-Ilkowska and Zdanowski 1988a, b, Protasov et al. 1994, 1997, Zdanowski 1994, Socha and Zdanowski 2001). By connecting the lakes with a system of water uptake and post-cooling water discharge canals, and also artificial retention reservoir and ponds, biotopes were created here that are advantageous for rheophilous mollusks introduced from other environments, including the Chinese mussel, *Sinanodonta woodiana* (Lea) (Kraszewski 2006, Kraszewski and Zdanowski 2007) and *Melanoides tuberculatus* (Müller) (Piechocki et al. 2003). Although hard substrates are normally a limiting factor in the development of *D. polymorpha* populations under natural conditions, they were not in the Konin lakes (Lewandowski et al. 1997, Lewandowski 2001).

The first reports of the zebra mussel as a component of the benthic fauna of the Konin lakes were published by Leszczyński (1976) and Berger and Dzięczkowski (1977) based on studies conducted in the second half of the 1960s. The occurrence of larvae in the pelagic zones of the lakes, the growth rate of the settled mussels, and the density of settlement by various age groups were studied in subsequent decades by Stańczykowska (1976), Kornobis (1977), and Stańczykowska et al. (1988). Substantial decreases in growth rate were noted in sublittoral aggregations in comparison with those in the lake littoral zones. Life span was also noted to be limited to three to four years in the environments with intensely heated waters, while the age structure was dominated by juvenile specimens. Population density in the lake system fluctuated widely from 900 to 13000 indiv. m^{-2}.

A fuller description of the zebra mussel inhabitation of the Konin lakes system was obtained in the 1993-1994 period (Protasov et al. 1994, 1997, Sinicyna et al. 2001, Protasov and Sinicyna 2002). All of the lakes and canals of the system were explored by scuba divers, who noted that zebra mussels developed better at depths to 3.0 m in the shallower lakes (Licheńskie, Gosławskie, Pątnowskie), and at depths to 7.0 m in the deep lakes (Mikorzyńskie, Ślesińskie). Aggregations of zebra mussels settled forming druses (Protasov and Sinicyna 2002). In the assemblages of periphyton and benthos, the zebra mussel was the functional and structural dominant because of its substantial share in effectively filtering water and improving water purity, among other reasons (Protasov et al. 1994, 1997, Sinicyna et al. 2001). Factors that limited the density of zebra mussel populations included oxygen deficits in the sublittoral and profundal zones, the lack of sufficient areas of hard substrate at habitat sites, and increases of summer water temperature that exceeded 30°C. Nevertheless, factors that stimulated the development of this population included water flow rate in the system, food resources of the appropriate quality and quantity, sufficient quantities of substrate area in canals for larval settlement; and the occurrence in summer of zones with water within the optimal temperature range of 26-28°C (Protasov and Sinicyna 2002).

The aim of the work was to study the variation in the structure of the zebra mussel population in the Konin lakes system in the 1993–2006 period. The mussel population was analyzed based on integration characters (density, biomass) and a range of structural indicators (size, age, sex). Data from the 1993-1998 period were used in the study (Protasov et al. 1994, 1997, Protasov and Sinicyna 2002).

MATERIALS AND METHODS

The zebra mussel population was studied at six permanent study stations, as follows: Lake Licheńskie (area 147.6 ha, max. depth. 12.6 m), Lake Ślesińskie (area 152.3 ha, max. depth 24.5 m); discharge zone of post-cooling waters from the power plant into the initial cooling reservoir (area 75.0 ha, max. depth 3.0 m); four stations in the canals with a total combined length of 26 km (Fig. 1, Table 1). For comparison, samples of zebra mussels were collected at stations in the Warta-Gopło canal outside of the system i.e., at stations in the Warta River water inflow and the outflow from Lake Ślesińskie to Lake Gopło.

The mussels were collected with the free diving method. After a visual exploration to determine a typical zone for a given habitat, mussels were collected underwater by hand with all the substrates (mussels, empty mussels, single rocks, wood) using a 50 x 50 cm frame (in at least three replicates) and then recalculated for one m^2 of bottom

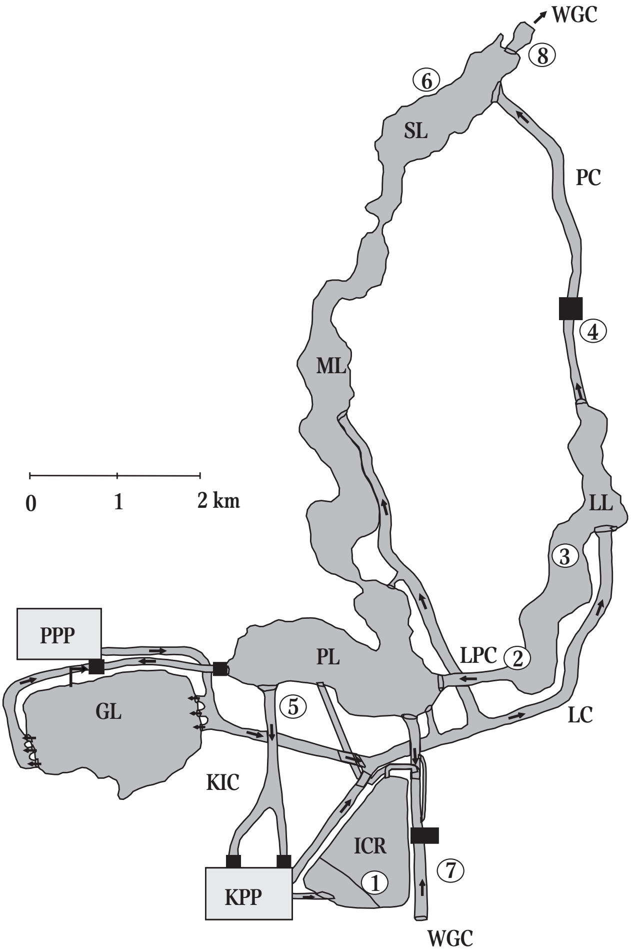

Fig. 1. Study station of the *Dreissena polymorpha* in the Konin heated lake system. PPP – Pątnów Power Plant, KPP – Konin Power Plant, LL – Licheńskie Lake, SL – Ślesińskie Lake, ML – Mikorzyńskie Lake, PL – Pątnowskie Lake, GL – Gosławskie Lake, ICR – Initial cooling reservoir, LPC – Licheńsko-Pątnowski Canal, PC – Piotrkowicki Canal, LC – Licheński Canal, WGC – Warta-Gopło Canal, KIC – Konin Power Plant intake canal.

area. Mussels that were attached to the rocks reinforcing canal embankments and from the dams and barriers were collected in three replicates from a surface area of 10 cm^2 and then recalculated to one m^2 of the given substrate.

Length and weight measurements of the zebra mussels were performed to the nearest 0.1 mm and 0.001 g (shell wet weight), respectively. Juvenile mussels were measured with a binocular micrometer eyepiece, while adult specimens were measured with a slide caliper. The size structure of post larval zebra mussel specimens (0.25-0.95 mm) were divided into 0.25 mm length classes; juveniles (1.0-5.5 mm) into 0.5 mm length classes, and adult specimens (> 5.5 mm) into 5 mm classes. The analysis of the size structure of the mussel population was based on determining the abundance of size groups and calculating the diversity in the size structure. The Shannon-Weaver diversity index (Shannon and Weaver 1949) that was modified by Mikhalevich and Emel'anov (1979) to evaluate the size structure populations (H'N) was applied. The studies of the juvenile segment of the population was conducted in the summers of the 2001-2002 period on various substrates (live mussels, shells, glass, rocks, wood).

TABLE 1

Description of habitats of *D. polymorpha* occurrence in the Konin lakes system in summer during the 1993-2006 period. (See Figure 1 for location of study stations)

Station		Biotope type	Depth (m)	Mean annual water temperature (°C±SD)	Water hydrodynamics	Substrate
1	Initial cooling reservoir	dam	0.6-1.5	20.6±0.9	lotic	rock
		bottom behind the dam	2.0	20.6±0.9	lotic	mussel
2	Licheńsko-Pątnowski Canal	bottom	2.0-2.5	16.4±0.8	lotic	varied*
3	Lake Licheńskie	bottom	3.0	16.0±0.8	lentic	rock
			1.2-3.0		lentic	varied*
4	Piotrkowicki Canal	bottom	1.1-3.0	15.2±0.9	lotic	varied*
5	Konin Power Plant intake canal	rock embankment reinforcement	2.1-2.8	14.3±0.7	lotic	rock
		bottom	3.0-3.3	14.3±0.7	lotic	varied*
6	Lake Ślesińskie	bottom	2.0	13.0±0.7	lentic	rock
			2.7-4.5	13.0±0.7	lentic	varied*
7	Warta-Gopło Canal	bottom	1.0	13.0±0.7	lotic when locks operating	mussel
8	Warta-Gopło Canal		2.0-2.5	13.0±0.7	lotic	rock

**mussel, empty shells, rock*

The effective temperature sum was calculated with the Alimov method (1981) with mean monthly temperatures above 10°C (Stawecki et al. 2007). The length of the period in which the zebra mussels could develop was determined as the number of days when water temperature exceeded 10°C.

Analyses of the sex structure of *D. polymorpha* were performed for the summers in the 2001-2006 periods. Sex was determined with the L'vova and Makarova (1990) method with the microscopic analyses of sex product preparations squeezed from their gonads. The number of mussels used in the study was proportional to the size structure of sexually mature mussels (> 5.5 mm). In total, 5000 specimens were examined.

The age of zebra mussels was determined based on the annual rings in the shells (Wiktor 1969), and also from the signs on the septa (Antonov 1979), which is the division between the inner part of the shell and the surface of the mussel shell to which the anterior adductor muscle is attached.

RESULTS AND DISCUSSION

HABITATS OF ZEBRA MUSSEL

The habitats settled by zebra mussels were transformed thermally depending on the amount of heat that was delivered by the power plant discharge waters. Only the habitats in the northern part of Lake Ślesińskie approximated natural conditions. The mean annual water temperature at the six study stations where zebra mussels occurred ranged from 13.0 to 20.6°C, and the water flow in the lotic zone fluctuated from 0.05 to 0.32 m s^{-1} (Table 1). The maximum thermal load that the *D. polymorpha* population was subjected to in the heated zone was 1.7 times higher in comparison to the minimum thermal load. The period during which *D. polymorpha* could develop ranged from 203 to 322 days, including from 50 to 92 days in spring (Table 2).

TABLE 2

Thermal loads and vegetative time period of the *D. polymorpha* population in the Konin lake system in the 1993-2006 period

	Station	Annual effective temperature (degree days±SD)	Spring effective temperature (degree days±SD)	Vegetation time period (days±SD)	Spring vegetation time period (days±SD)
1	Initial cooling reservoir	6740±857.7	1819±160.9	322±23.9	92±0.0
2	Licheńsko-Pątnowski Canal	5072±214.5	1284±332.0	240±20.5	70±23.2
3	Lake Licheńskie	4956±168.6	1178±277.3	239±26.0	64±16.4
4	Piotrkowicki Canal	4681±272.5	1140±185.2	236±23.9	64±9.3
5	Konin Power Plant intake canal	4386±327.5	1008±270.8	220±27.5	59±18.3
6	Lake Ślesińskie	4003±282.9	843±264.0	203±15.1	50±15.1

The length of the spring development period of mussels outside the system (station 7) did not usually exceed 61 days (64% of the mussels). In summers following longer and cooler springs, like those in 1996 and 2001-2003, this period was the shortest (31 days). The development of zebra mussels in the discharge zone of the heated waters was possible in the winter period (January-February) when the thermal regime was under 10°C. It was, however, impossible in summer at temperatures exceeding 30°C; this is when mass mortality was noted in this population. The life cycle of the *D. polymorpha* population inhabiting this zone exhibited an original life cycle; following the summer elimination, it resettled again in September on the substrata when the temperature decreased to 24°C and continued to grow from fall to summer, with the exception of rare periods in winter, when temperatures fell to below 10°C, which halted the development process.

ZEBRA MUSSEL POPULATION DYNAMICS

The variability in the thermal regime of the Konin lakes waters was the primary differentiating factor for the zebra mussel populations inhabiting the various zones of this system (Table 3).

TABLE 3

Description of the *D. polymorpha* population in the Konin lakes ecosystem in the summers of the 1993-2006 periods

Station	Substrate	Abundance (thous. indiv. m^{-2})	Biomass (kg m^{-2})	Range of mean individual weight (g)	Variation in size structure (H'N)
Initial cooling reservoir	dam	2.73-166.66	1.11-18.81	0.045-0.407	0.657-2.193
	bottom, beyond dam	0.39-7.93	0.04-1.69	0.086-0.184	0.744-1.946
Licheńsko-Pątnowski Canal	bottom, varied substrate	0.63-30.85	0.10-3.66	0.075-0.256	1.109-2.136
Lake Licheńskie	bottom, varied substrate	0.27-40.78	0.03-2.55	0.035-0.213	1.225-2.072
	rock	13.36	2.55	0.035	1,335
Piotrkowicki Canal	bottom	0.98-111.85	0.05-12.12	0.038-0.457	1.171-2.263
Konin Power Plant intake canal	rock embankment reinforcement	3.83-186.38	0.35-3.96	0.020-0.245	0.956-1.993
	bottom	0.42-58.06	0.05-18.16	0.019-0.414	1.300-2.047
Lake Ślesińskie	rock	103.08	12.49	0.121	1.390
	bottom	0.08-25.63	0.02-5.38	0.143-0.500	1.303-2.180
Warta-Gopło Canal	mussel	0.17	0.12	0.721	2.515
Warta-Gopło Canal	rock	5.08-6.60	4.68-10.31	0.921-1.562	2.272-2.340

More intense development was noted most frequently in lotic habitats, while in the lakes it was noted only in the vegetative seasons when spring was warmer and summer was cooler. The maximum density of zebra mussel settled on the bottom usually varied with relative distance from the heated water discharge from the power plant.

The highest maximum mussel density (111,850 indiv. m^{-2}) was noted in the canal that drains waters from Lake Licheńskie (station 4), where 80% of the bottom area was covered densely with mussel druses. Lower maximum mussel density (2-4 times) was noted on the bottoms of the remaining stations, and the lowest (22 times) was noted in the zone where the warmest post-cooling water was discharged from the Konin Power Plant into the initial cooling reservoir (station 1). The density of zebra mussels that settled on rocks was higher at a maximum range from 103,080 to 166,660 indiv. m^{-2} in both the warmest zone (station 1), and in the coolest zones (stations 5 and 6). The lowest density of zebra mussels fluctuated from 0.08 to 0.90 thous. indiv. m^{-2}; this was basically the same at other stations.

The maximum zebra mussel biomass, on both the bottom and rocks, ranged widely from 2.55 to 18.16 kg m^{-2}. As a rule, higher mussel biomass was noted in the cooler flow-through zones, which included the canal draining water out of Lake Licheńskie (station 4) and that supplying water to the Konin Power Plant (station 5). Irregular, but substantial, zebra mussel biomass was confirmed on the submerged dam (station 1), which was in the warmest zone of the initial cooling reservoir that is supplied with post-cooling water from the Konin Power Plant.

SIZE STRUCTURE AND POPULATION DENSITY

Dimension-age characteristics are widely accepted as indicators of the development of a mussel population. Under natural conditions the structure of mussel populations is usually of a bimodal distribution (Marvin and Howell 1997, Miller and Payner 1997, Morrison et al. 1997), which is evidence that conditions are stable and advantageous for mussel development (Stańczykowska 1977, 1997, Lewandowski 2001).

Changes in the density of the zebra mussel population during the vegetation period in the Konin heated lakes ecosystem depended on two alternate processes; namely the recruitment of juveniles and the elimination of a portion of the adult population. The peak of population abundance was most frequently the result of the massive settling of larvae. The most important role here was played by age 1+ individuals and those that had settled in the fall of the previous year. During the vegetation period, the older population had already been supplemented by juveniles to a small degree. Following the conclusion of reproduction, mortality determined their abundance.

During the summer periods of 1993-2006, the size structure of *D. polymorpha* was characterized by the distinct domination of one size group and sometimes the co-domination of several size groups more or less in equal ratios (Fig. 2). First, mussels from group I measuring from 1 to 5.5 mm (34%) dominated distinctly, then they were co-dominants.

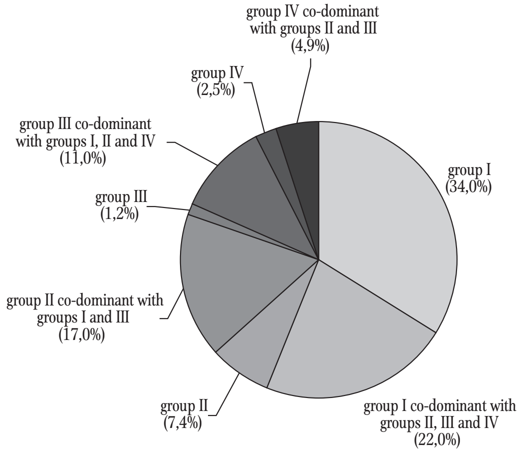

Fig. 2. Frequency (%) of domination and co-domination of size groups (I – 1.0-5.5 mm; II – 5.6-10.5 mm; III – 10.6-15.5 mm; IV – 15.6-20 mm) in the size structure of *D. polymorpha* in the Konin lakes ecosystem in the summers of the 1993-2006 period.

The significant dependence (r^2 = 0.78, $P < 0.05$) between mean individual weight, described as the ratio of total abundance to total biomass, and the variation in size structure (H'N) indicates that the ecological state of the zebra mussel population inhabiting particular stations is variable (Fig. 3). Younger populations had relatively low indices of population ecological state (weight = 0.019-0.086 g, H'N = 0.657-1.335), while in aging populations they were higher (weigh = 0.121-0.500 g, H'N = 1.303-2.263). The highest population ecological state indicator was noted in a population inhabiting an environment on the outskirts of the system (weight = 0.721-1.562 g, H'N = 2.272-2.515).

Greater juvenile domination can be anticipated in summer in the heated, lotic environments (Fig. 4). The share of juveniles in the overall number of zebra mussels was significantly correlated not only with settlements of mussels on hard substrates (r^2 = 0.86, $P < 0.05$), such as rocks reinforcing embankments, dams, and single large rocks. This dependence was not confirmed for settlements on empty shells, small rocks, or fragments of wood ($P > 0.05$). These observations confirm the theory that the presence of appropriate substrates for larval settling and continued development might

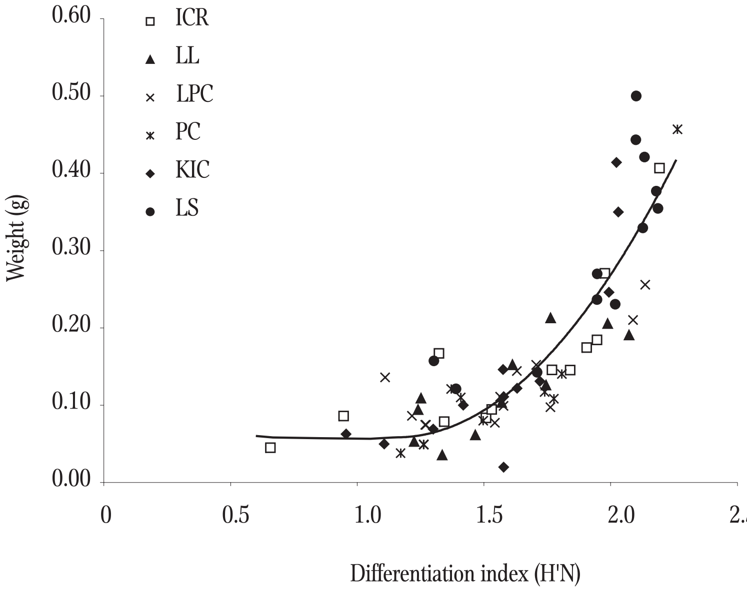

Fig. 3. Tendencies of change in mean weight (g) of the *D. polymorpha* population depending on size structure variations (H'N) in the Konin lakes system in the summers of the 1993-2006 period. Study stations as in Figure 1.

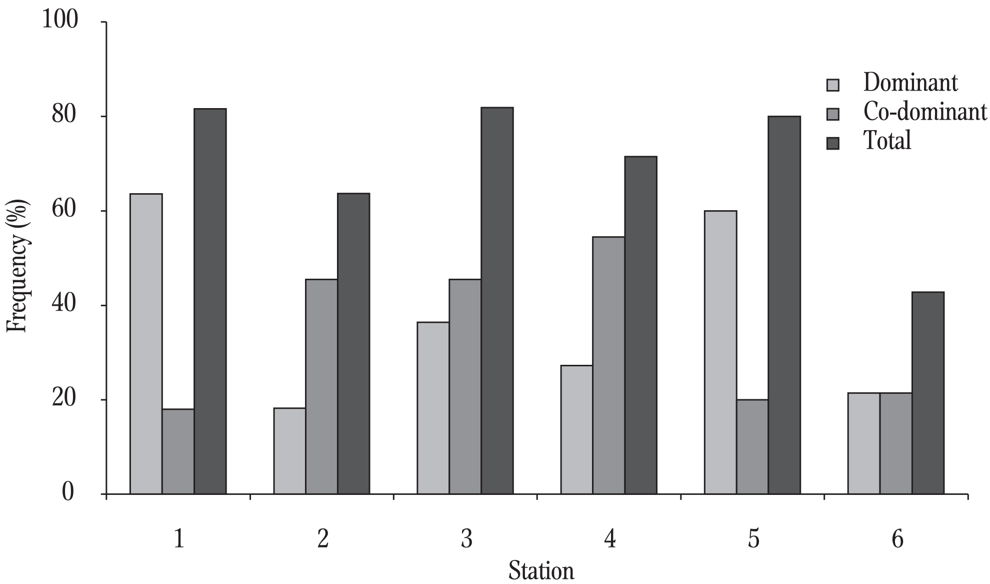

Fig. 4. Frequency (%) of domination and co-domination of juveniles (1.0-5.5 mm) in the exchange structure of *D. polymorpha* in the summers of the 1993-2006 period. Study stations as in Figure 1.

be one of the fundamental factors contributing to the occurrence of the mature segment of the population in substantial numbers (Stańczykowska et al. 1988).

The most advantageous conditions for larval settling and juvenile survival usually occurred in lotic environments that were moderately heated, were rich in druse-type substrates, with summer temperatures of 24-26°C. Variation in the juvenile size structure was even greater here (H'N = 2.857-3.319) in comparison to that achieved in lentic conditions (H'N = 1.901-2.467) (Table 4).

TABLE 4

Sex structure of *D. polymorpha* in the Konin lakes ecosystem in the summers of the 2001–2005 period

Station		Females (%) (±SD)	Males (%) (±SD)	Hermaphrodites (%) (±SD)
Initial cooling reservoir	damn	100.0		
	reservoir	71.4±1.0	1.91±0.5	26.7±3.0
	lock	54.1±2.0	41.8±3.1	4.0±1.5
Licheńsko-Pątnowski Canal		70.3±10.5	24.5±14.8	5.2±4.8
Lake Licheńskie		56.3±17.6	44.0±6.5	13.6±10.9
Piotrkowicki Canal		54.9±5.1	43.5±5.4	0.0-5.9
Konin Power Plant intake canal		50.5±7.1	48.2±6.7	1.3±1.7
Lake Ślesińskie		54.5±5.0	37.8±4.7	9.9±4.1

Water turbulence also sometimes increased the survival of juveniles in environments that were heated intensely, i.e., in the initial cooling reservoir for post-cooling waters (station 1). The highest frequency of juvenile *D. polymorpha* was noted here in the summers of 1997 and 1998 (up to about 2 million indiv. m^{-2}) on the side of the submerged dam when near-bottom water upwelled after the input of post-cooling waters increased the possibilities of larvae settling on the appropriate substrate and their survival in more advantageous thermal, oxygen, and feeding conditions. Apparently, increasing the size structure diversity of juveniles is noted also among the zebra mussel that settle on live *S. woodiana*, which inhabit lentic environments. The survival of the zebra mussels could be greater with more dynamic conditions, higher water turbulence through forced filtration activity near the habitat of large filtrators.

RELATIONSHIP BETWEEN ABUNDANCE AND BIOMASS OF ZEBRA MUSSELS AND BIOTOPE THERMAL CONDITIONS

The density dynamics of the *D. polymorpha* population inhabiting particular habitats in the lake system was significantly dependent on water temperature variability. In moderately heated habitats (stations 2, 3, 4, 5), mussel density was usually positively correlated with the effective temperature sum in the spring (r^2 = from 0.74 to 0.85, $P < 0.05$), while at the least heated habitat (station 6) it was correlated with the effective temperature sum in the summer ($r^2 = 0.88$, $P < 0.05$). A highly significantly positive correlation between mussel abundance and water temperature depending on station (r^2 = from 0.85 to 0.97, $P < 0.05$) was noted primarily in the population inhabiting the bottom of the canal that drew water into the power plant (station 5), in which the temperature was lower but the flow rate substantially higher. The maximum mussel density (43,850-58,060 indiv. m^{-2}) was noted here in the season that had the highest annual effective temperature sum (4588-5046 degree days) and the longest vegetation period (245-275 days), including the spring period as well (92 days). The density of zebra mussels in the zone with the highest degree of heating (station 1) was negatively correlated with temperature ($r^2 = -0.99$, $P < 0.05$). Higher mussel density (140,18-166,660 indiv. m^{-2}) was only noted in the lower effective temperature sum range (4075-4249 degree days).

Changes in the biomass of zebra mussels in particular habitats was positively correlated with water temperature (r^2 = from 0.73 to 0.92, $P < 0.05$). Only at station 1 was the biomass of *D. polymorpha* negatively correlated with water temperature ($r^2 = -0.92$, $P < 0.05$), where increased water temperature caused a decrease in the biomass of zebra mussels.

IMPACT OF TEMPERATURE ON THE ZEBRA MUSSEL SEX STRUCTURE

Most dioecious mussels inhabiting natural environments that have not been transformed anthropogenically occur at even sex ratios (Dillon 2000). This rule does not apply to polluted environments (Shurova and Stadniczenko 2002), including that of the intensely heated Konin lakes system (Table 5).

In the current study, only the *D. polymorpha* population inhabiting the least heated environment exhibited an equal share of males and females. A greater share of females was confirmed in both the lentic and lotic environments near the heated water discharge.

An extreme example of this was the 100% share of females noted on the flood dam in the initial cooling reservoir for Konin power plant discharge waters. Simultaneously, with a higher thermal regime at an effective temperature sum of 7676 degree days, the mussels were substantially less abundant and no mussels were noted in this environment in subsequent years. As Dillon (2000) reported, the share of hermaphrodites was higher in lentic conditions; just slightly above 4% is considered to be the norm for inland water bivalves. The share of females increased at higher temperatures (r^2 = 0.73, P < 0.05), while that of males decreased (r^2 = -0.79, P < 0.05) (Fig. 5). This dependence indicated that this mechanism increases the reproductive capability of a population in disadvantageous thermal conditions.

TABLE 5

Diversity of *D. polymorpha* juvenile size structure (mean ± SD) in the Konin lakes ecosystem in the summers of the 2001-2003 periods

Station	Substrate	Diversity of size structure (H'N)
Initial cooling reservoir	rock	2.454±0.209
Licheńsko-Pątnowski Canal	glass	3.221
	mussel	3.064±0.209
	druse	3.436
Lake Licheńskie	mussel	2.298±0.002
	rock	1.694±0.133
Piotrkowicki Canal	mussel	2.754
Konin Power Plant intake canal	rock	3.203
	druse	2.850
Lake Ślesińskie	mussel	2.089±0.006
	rock	2.033±0.100

CONCLUSIONS

The decreasing frequency of occurrence of larger individuals, as well as older ones, noted in the 1970s, was a peculiarity distinguishing the *D. polymorpha* population inhabiting the heated Konin lakes (Stańczykowska 1976). Observations from the most recent decade indicate that the life expectancy of this mussel is decreasing, and that apparently this is happening progressively along with long-term heating of this system. The maximum zebra mussel age, determined based on shells collected from the bottom of the least intensely heated lake, is estimated to be 6-7 years. Currently, the maximum mussel age in this lake is 4-5 years, in the moderately heated zones it is two years, and in the heated water discharge zone just one year. More intense growth in this last area allowed the mussels to achieve sizes comparable to two- to three-year-old specimens living in natural conditions (Stańczykowska 1976, Lewandowski 2001). The average size of live mussels was 1.5-times smaller, weight was fourfold lower, and maximum length was 6 mm shorter, which meant they barely obtained the maximum size limit

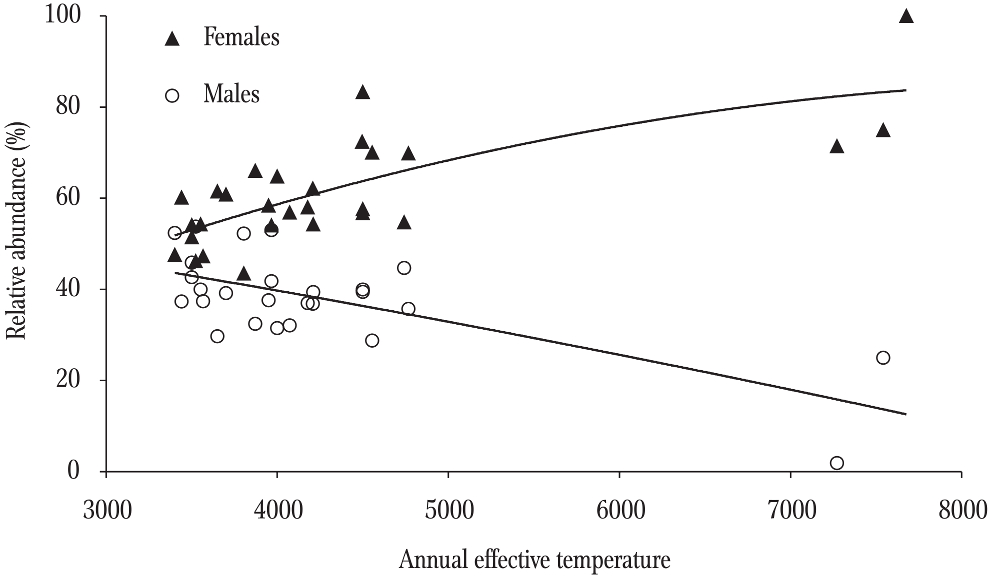

Fig. 5. Dependency between the share of females and males in the population of *D. polymorpha* and the effective temperature sum in the Konin lakes ecosystem during the summers of the 2001-2006 period.

(27.0-39.5 mm) of mussels occurring in natural Polish lakes (Lewandowski et al. 1997, Lewandowski 2001).

The elimination of the zebra mussel from the system happened mainly from the heat load in the intensely heated environment. The greatest risk to the population was a heat load that exceeded 5900 degree days. Zebra mussel abundance was then negatively correlated with water temperature. Indexes that contributed to lowered zebra mussel resistance to this stress (i.e., symptoms of depression), were the same as those reported by Rajagopal et al. (1997) and included a simplified population structure, thus fewer age groups, a disturbed sex ratio, and a decrease in the occurrence of individuals of maximum body size.

The withdrawal of the mussel could also happen with progressing water eutrophication as was demonstrated by Stańczykowska (1997) and Lewandowski (2001). Decreasing water transparency, a lack of food of the appropriate size due to the growing domination of large chain-forming phytoplankton, and also the muddying of habitat substrates by matter sedimentation (as happened in the initial cooling reservoir for heated waters from the Konin power plant) all contributed to the withdrawal of the zebra mussel from the Konin lakes system.

ACKNOWLEDGEMENTS

The study was the effect of contractual cooperation between the Inland Fisheries Institute in Olsztyn and the Institute of Hydrobiology, National Academy of Sciences of Ukraine in 2005-2008.

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Received - 08 January 2007

Accepted - 11 July 2007

STRESZCZENIE

ROZWÓJ POPULACJI ZEBRA MUSSEL, *DREISSENA POLYMORPHA* (PALL.) W EKOSYSTEMIE PODGRZANYCH JEZIOR. I. ZMIANY STRUKTURY POPULACJI

Celem badań była charakterystyka populacji małży zebra mussels, *Dreissena polymorpha* (Pall.) w systemie jezior konińskich w latach 1993-2006. Suma rocznych efektywnych temperatur rozwoju populacji zmieniała się w poszczególnych biotopach tego ekosystemu w szerokim zakresie od 3720 do 7600 stopniodni, a okresu wegetacyjnego – od 188 do 345 dób, w zależności od ich położenia względem zrzutu wód podgrzanych z elektrowni. Populacje występujące w strefie najcieplejszej systemu charakteryzowały się uproszczoną strukturą populacji, małą ilością grup wiekowych, mniejszą maksymalną masą osobniczą i niezrównoważoną strukturą płci. Występowanie zebra mussels w tych siedliskach było ujemnie skorelowane z temperaturą wody. Obfitość *D. polymorpha* w strefach o umiarkowanym stopniu podgrzania wód była natomiast dodatnio skorelowana z sumą efektywnych temperatur.