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MORPHOLOGICAL VARIATION IN THE CHINESE CLAM *SINANODONTA WOODIANA* (LEA, 1834) IN THE HETEROGENEOUS CONDITIONS OF THE KONIN HEATED LAKE SYSTEM IN CENTRAL POLAND

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ABSTRACT: In the mid 1980s, the Chinese clam *Sinanodonta woodiana* (Lea, 1834) from SE. Asia was accidentally introduced in the Konin heated lake system (central Poland) from Hungary, along with fish stocking material. Currently, it inhabits abundantly the littoral zones of the five lakes that comprise the system, the initial cooling basin, and most of the associated intake and discharge canals. The considerable heterogeneity of its habitats in the system affects the morphological variation of its shells. The shell morphology, size, colour and growth rate are shaped by environmental factors, of which temperature, water flow intensity, and substrate type are the most important. The largest and heaviest specimens were found in the warmest habitats with the fastest water flow. Specimens with shells up to 160 mm long constituted most of the population, while in moderately heated areas the length was up to 125 mm, and in the coolest areas – 115 mm. The maximum individual weight was 900 g.

KEY WORDS: Unionidae, *Sinanodonta woodiana*, shell morphometry, variability, habitat, heated waters

INTRODUCTION

The unionid *Sinanodonta woodiana* (Lea, 1834) is a new species to the Polish mollusc fauna. It was accidentally introduced in Poland from Hungary in the mid 1980s, with stocking material of the herbivorous silver carp *Hypophthalamichthys molitrix* (Valenciennes, 1844) and grass carp *Ctenopharyngodon idella* (Valenciennes, 1844) (PROTASOV et al. 1993, ZDANOWSKI et al. 1996, KRASZEWSKI & ZDANOWSKI 2001). Since introduction, it has inhabited the ecosystem of the Konin heated lakes in central Poland, where elevated water temperature and turbulence provide good conditions for its functioning and development. The variety and complexity of its habitats – intake and discharge canals, cool and warm lakes, the initial cooling basin, and the ecotone zone, favour its biomorphological variation.

The aim of the study was to analyse the variation in shell morphology (size, shape, color) and body mass of *S. woodiana* inhabiting different anthropogenic habitats in the Konin heated lake system and its associated canals.

STUDY AREA

The Konin lake system is situated in central Poland in the Wielkopolsko-Kujawskie Lakeland, 20 km north of Konin, in the Lake Gopło catchment area (KONDRACKI 1998). The functioning of the Konin heated lake system is associated with two power plants – the Konin Electric Power Plant that has been in operation since 1958, with a nominal water intake and discharge of 25 m^3s^{-1}, and the Pątnów Electric Power Plant, with a nominal capacity twice the size, which was put into operation in 1970. With a total combined surface area of 13 km^2 and a volume of 60 million m^3, the Konin lake system is composed of lakes Ślesińskie, Mikorzyńskie, Pątnowskie, Licheńskie, and Gosławskie. They are characterised by varied morphology, trophic status, mixing, and thermal regime (Table 1) (Hillbricht-Ilkowska & Zdanowski 1978, 1988, Zdanowski 1989, 1994). The Konin lakes are connected by a system of power plant water intake and discharge canals which are 26 km long (Table 2). The initial cooling basin, which is supplied by post-cooling waters from the Konin plant, has been part of the system since 1976 (Table 1).

The water level in the system is controlled by two chamber locks, located in the Warta-Gopło canal. Water flows in the system are regulated by the Pątnów, Przesmyk, Konin, and Piotrkowice intermediate pumping stations (Fig. 1).

There are two water circulation systems in the Konin lakes. During periods of lower temperature, from September to May, the "short" system is in operation. In the summer, the "long" system is operational, which means that Lake Ślesińskie and the northern section of Lake Mikorzyńskie are included in the cooling system when the intermediate pumping station on the Piotrkowicki Canal is switched on (Fig. 1). This is necessary during warmer periods, when additional water cooling provided by these basins is needed because of the less effective heat exchange.

METHODS

The biomorphological analysis of *S. woodiana* was conducted in 1999–2002. The sampling sites were selected with the scuba diving method described in Protasov et al. (1982). Following the initial description of the bottom morphometry of various sections of canals and the littoral zone of the lakes (width, depth, bottom profile), water flow rate was measured and the types of substrata on which the clams had settled were identified. The information was used to select sites which would be representative of the clam's habitats in the lakes, canals, and initial cooling basin (20 sites). Specimens from the ten most representative sites with varied habitat conditions, where observations were conducted continuously (4 years), were subject to a detailed biometrical analysis. These sites were: Lake Ślesińskie (site 1), Lake Licheńskie (5), initial cooling basin (6, 7, 8), Konin Power Plant intake canal (10), Piotrkowicki Canal (15), Licheńsko-Pątnowski Canal (16), Warta-Gopło Canal (17), Licheński Canal (18), Konin Power Plant discharge canal (20) (Fig. 2).

Table 1. Limnological, morphometric, and hydrological characteristics of the Konin heated lake system and the initial cooling basin; data from Inland Fisheries Institute (IFI) and Pątnów–Adamów–Konin Electric Power Plants (ZE PAK)

Index	Unit	Lake Ślesińskie	Lake Mikorzyńskie	Lake Pątnowskie	Lake Licheńskie	Lake Gosławskie	Preliminary cooling reservoir
Limnological type*	–	eutrophy, dimixis	β-mezo/eutrohy, dimixis	eutrophy, polymixis	eutrophy, monomixis	eutrohy, polymixis	eutrophy, polymixis
Surface area P	ha	152.3	251.8	282.6	147.6	454.5	~ 75
Water volume V	$\times 10^3$ m^3	11,550	29,050	7,255	6,712	13,485	1,800
Maximal depth G_{max}	m	24.5	36.5	5.5	12.6	5.3	4.2
Average depth G_{mean}	m	7.6	11.5	2.6	4.5	3.0	2.5
Shore-line development L	m	11,500	15,520	11,910	12,660	11,330	–
Active-bottom surface	%	55	35	100	90	100	–
Direct catchment area	km^2	65.2	24.3	9.5	20.0	153.9	–
Water retention **	D	14 (6–30)	9 (5–16)	4 (3–6)	3 (2–5)	5 (4–6)	3 (3–4)
Water temperature T **	°C	14.1 (0.6–27.0)	14.5 (2.5–31.5)	14.8 (2.3–30.0)	16.2 (4.2–31.5)	16.4 (5.5–28.5)	22.0 (6.0–33.0)

* Korycka & Zdanowski (1976)

** Data from 1999–2002; values of water retention in lakes Ślesińskie and Mikorzyńskie during operation of "long" water system May–September

The clams were collected at depths of 1–3.5 m, using a frame with a surface area of 0.25 m^2 (0.5 × 0.5 m), from a bottom surface area of at least 1 m^2. They were cleaned of periphyton and sediments in the laboratory, and left to dry on filtration tissue for 10 minutes. Shell measurements were taken to the nearest 1 mm with a slide caliper; these included the total length (L), partial length measured from the shell apex to the top of the wing (l), height measured from the umbo to the ventral shell edge (H), height measured between the top of the wing to the ventral shell edge (h), width (W), and annual increment (G) (Fig. 3). These measurements were used to determine the shell shape indices: H/L, W/L, W/H, l/L, h/H, h/L. WPS 1200C (Radwag) analytic scales (accurate to within 0.1 g) were used to determine the wet weight of live clams (M). After the measurements, the clams were released.

The clam habitats were described based on the analyses of measurements of flow rates in the canals and initial cooling basin, the granulometry and content of organic substances in bottom deposits, water temperature, and seston content. Water flow rates in

Table 2. Morphometric and hydrological characteristics of the canals of the Konin system (authors' own and ZE PAK data)

Canal	Length [km]	Depth [m]	Total width [m]	Average width of bottom [m]	Nominal water flow* [m^{3}s^{-1}]	Flow velocity [ms^{-1}]	Water temperature** [°C]	Canal characteristics
Konin Power Plant intake canal	1.50	3.8	15-30	6.0	25	0.32	14.7 (1.5-27.8)	earthen, embanked on both sides
West Pątnów Power Plant intake canal	2.64	2.6	20-35	16.0	23	0.14	15.3 (2.5-27.5)	along the northern shore of Lake Gosławskie, partially earthen and reinforced concrete embankments
East Pątnów Power Plant intake canal	1.87	4.5	20-30	10.0	28	0.90	20.1 (10.8-26.8)	along the northern and western shores of Lake Gosławskie, embanked on both sides, Przesmyk intermediate pumping station
Konin Power Plant discharge canal	0.75	3.8	15-30	13.5	25	0.12	22.5 (10.6-35.9)	along the initial cooling basin, embanked on both sides
Pątnów Power Plant discharge canal	4.25	4.0	20-40	16.0	53 (30)	0.28	23.5 (9.6-35.0)	embanked on both sides, three outlets to Lake Gosławskie
Licheński	5.21	4.0	15-40	14.0	55 (29)	0.17	21.2 (9.4-33.8)	partially embanked
Licheńsko-Pątnowski	0.50	3.0	15-25	6.0	6	0.11	(4.2-23.5)	partially earthen and stone embankments, partial water dam at the outflow of Lake Licheńskie
Wąsoski	5.57	3.3	15-30	12.0	15 (10)	0.09	(9.4-24.5)	partially reinforced concrete embankment (section at the outflow to Lake Mikorzyńskie)
Piotrkowicki	6.20	3.2	15-40	15.0	23	0.05	24.8 **** (18.0-30.5)	partially reinforced with fascine, the Piotrkowicki III stage pumping station, springborad water discharge to Lake Ślesińskie
Ślesińsko-Mikorzyński	0.25	2.8	25-30	14.0	20	0.02	(3.1-24.0)	numerous rocks on the bottom
Warta-Gopło	8.50	3.5	25-50	11.5	30	0.10***	(4.5-25.6)	fascine embankments, two chamber locks at Morzysław and Pątnów sailing canal

* Water flow in the last canal section in parentheses
** Data from the 1999–2002 period; range of values in parentheses
*** Water flow rate when the locks are open
**** Temperature when the "long" cooling system is operational

the canals and initial cooling basin were measured with a µP-TAD vane wheel flow sensor (Höntzsch Instrument GmbH), and temperature measurements were taken with a YSI 58 temperature probe (Yellow Springs Instrument Inc.). The seston content of the lake and canal water was determined by weight after filtering samples through GF/C filters. Bottom deposit samples 8–10 cm thick were collected with a benthic fauna box corer. Granulometric composition of the samples was determined with the sieve analysis method.

The significance of differences in the shell parameters, weight and age were analysed with the T-Tukey test for unequal sample sizes. The level of significance was α=0.05. Based on this, the probability and differences between the clam groups that characterised different sites were determined. The dependence among biomorphological traits was determined by analysing annual shell growth with the Pearson (r) correlation coefficient.

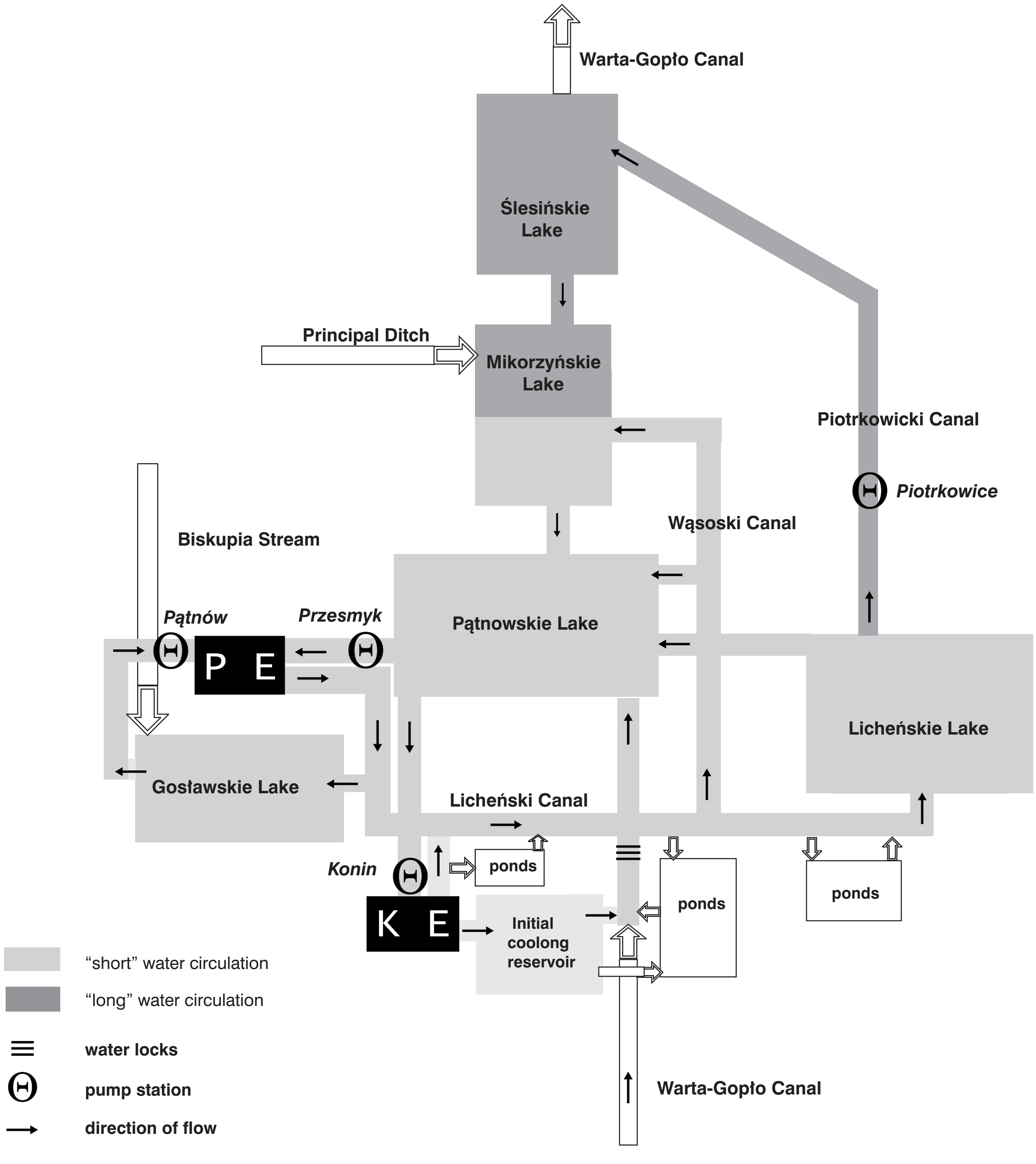

Fig. 1. The cooling systems of the Konin Electric (KE) and Pątnów Electric (PE) power plants

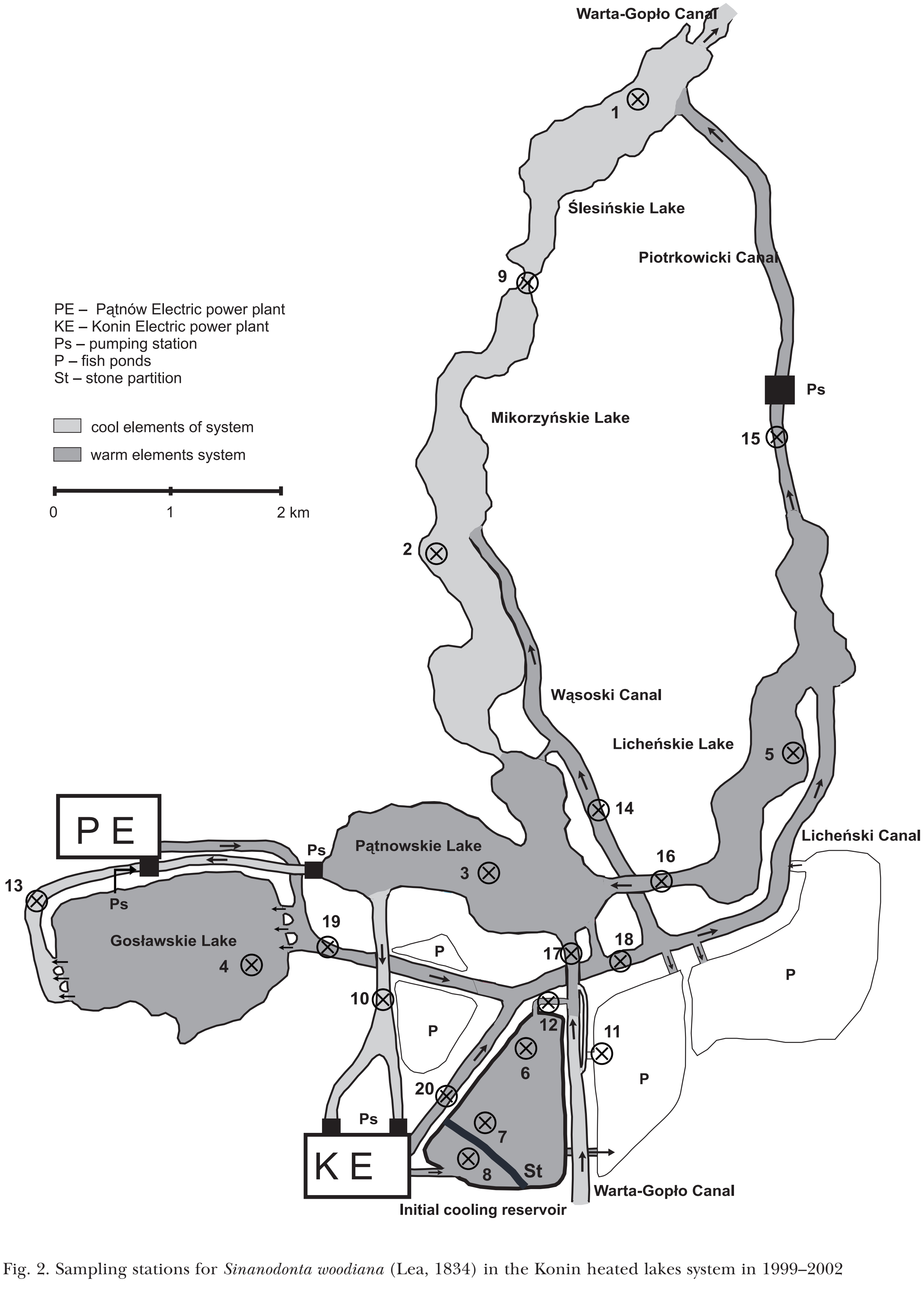

Fig. 2. Sampling stations for *Sinanodonta woodiana* (Lea, 1834) in the Konin heated lakes system in 1999–2002

RESULTS

SHELL MORPHOLOGY

The shell shape of *S. woodiana* from the Konin lake system was either oval or round-oval, with the umbo displaced anteriorly and a strongly protruding central section (Fig. 3). The shell edges of most individuals were not perpendicular to each other. The posterior edge rose above the apex towards the top. The wing was clearly defined. The shells of juvenile clams were thin and fragile, while those of older specimens were thicker and heavier, with clearly visible annual increments.

The shell colour varied depending on the type of substratum; it ranged from dark brown in places with dark, muddy bottom, through brown to shades of honey or olive green on bright, sandy substrata. Numerous, variously shaped incrustations, protrusions, and pearls were formed on the inside of the shells (Fig. 4).

The coolest zones of the system were dominated by specimens with a shell length range of 70–115 mm, in moderately heated zones – 90–125 mm, and in the warmest zones – 125–160 mm (Fig. 5). Thus, the total shell length increased with increasing water temperature.

In general, the clams in the cooler canals reached a length of up to 140 mm, while in the warmer canals they attained 160 mm. In the warmest canals, the shells were as long as 210 mm, and even 240 mm in the initial cooling basin. The smallest average shell size (L=72.7 mm) was characteristic of the clams from Lake Mikorzyńskie and the largest (L=160.8 mm) – from the initial cooling basin, in front of the stone barrier in the immediate vicinity of the post-cooling water discharge. The variation coefficient of the shell length of clams from various sites was on an average 15–20% (Table 3). The differences in shell length among the sites were significant (Table 4). Larger specimens (>200 mm) were noted less frequently and primarily in the warmest Konin power plant discharge canal, in the immediate vicinity of the post-cooling water discharge from the Konin power plant and in the initial cooling basin. Specimens aged 10–11 years achieved record lengths of 234 and 241 mm at weights of nearly 1 kg.

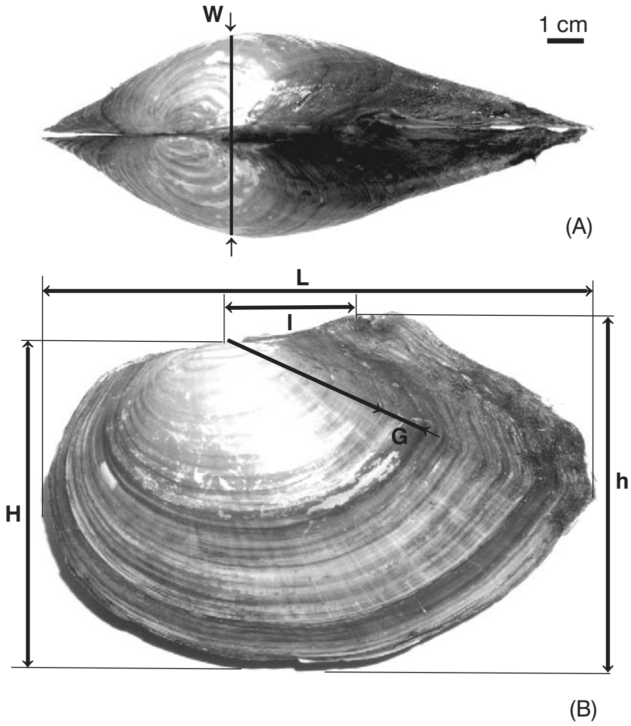

Fig. 3. Shell measurements of *Sinanodonta woodiana* (Lea, 1834), top view (A), side view (B): L – total length, l – partial length, H – umbo/ventral shell edge height, h – wing top/ ventral shell edge height, W – width, G – an-

The distance between the shell apex and the top of the wing (l), was highly variable (Table 3). The highest value (57.6 mm) was noted in the specimens from Licheński Canal.

The clams in the discharge zone of the initial cooling basin had the highest shells (H), the mean being 87.5 mm (Table 3). The clams in the warmer canal systems had somewhat lower shells (70.0–80.0 mm), while those with the lowest shells (47 mm) occurred in Lake Gosławskie. The shell height was significantly similar among the clams that occurred in Lake Licheńskie and in the intake canal of the Konin power plant, as was the case among the clams from the Warta-Gopło, Licheński, and Piotrkowicki canals, as well as those from the Konin power plant and Licheńsko-Pątnowski discharge canal (Table 4).

The wing height (h) was greater than the total height (H) in all sites, due to the rising posterior ridge of the shell (Table 3). The clams from Lake Licheńskie and the intake canals of the Konin power plant were similar in this respect, as were the specimens from the Konin discharge, Piotrkowicki, Licheńsko-Pątnowski, and Licheński canals (Table 4).

S. woodiana from the immediate vicinity of the water discharge into the initial cooling basin were the widest (W) (convexity), with the mean of 51.1 mm. Specimens from warm canals and Lake Ślesińskie had narrower shells (>40.0 mm), while the shell width was the smallest (mean 37.9 mm) in specimens from the mid section and the outflow zone of the initial cooling basin. The shell width was significantly similar among specimens from Lake Licheńskie, the initial cooling basin, the intake canal of the Konin power plant and the warm Warta-Gopło, Licheński, Konin power plant discharge, and Piotrkowicki canals, as well as the zone immediately adjacent to the initial cooling basin and the Licheńsko-Pątnowski Canal (Table 4).

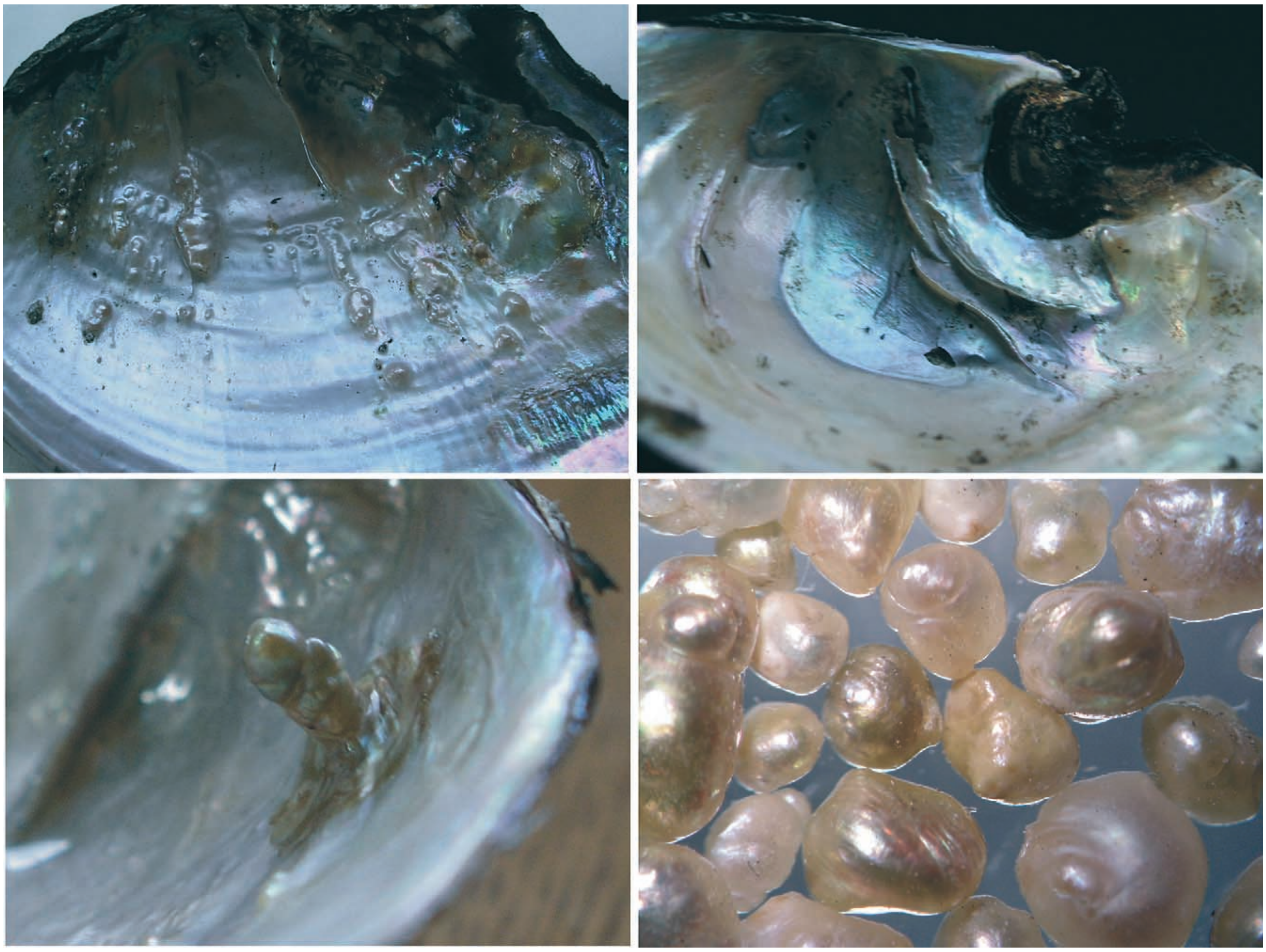

Fig. 4. Incrustations, protrusions and pearls of *Sinanodonta woodiana*

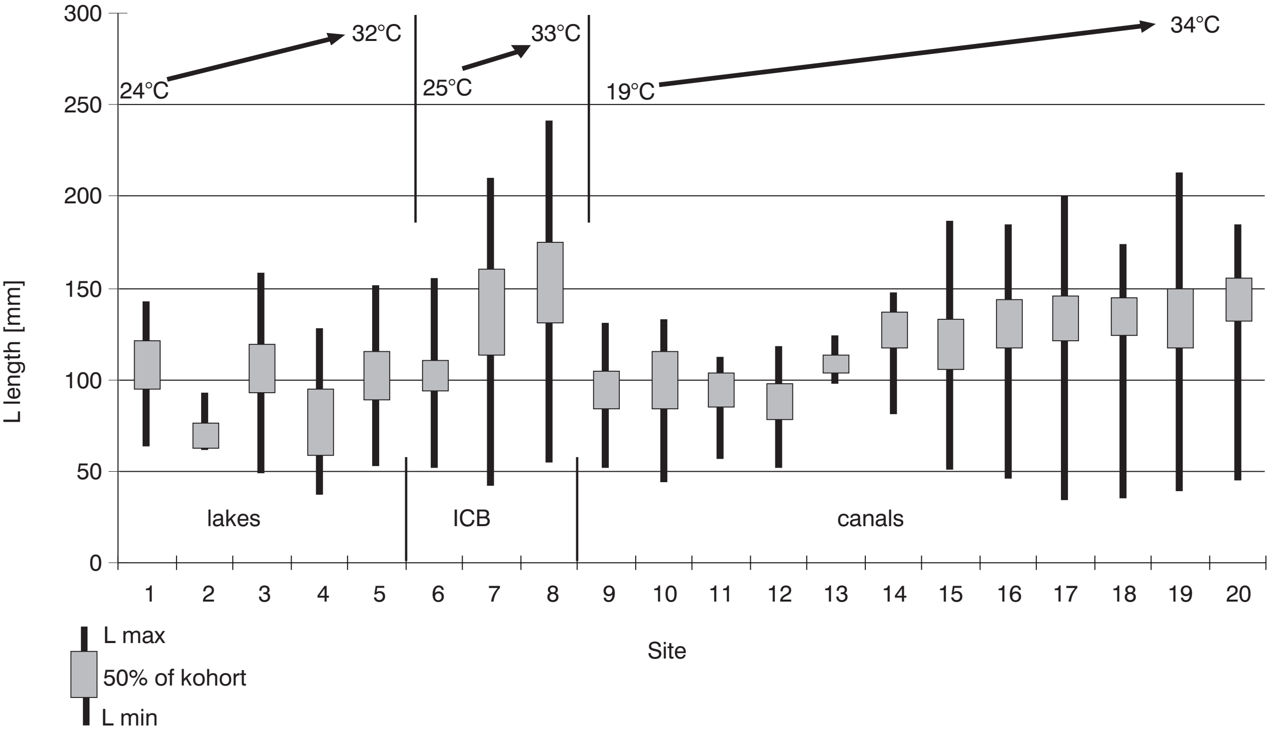

Fig. 5. Variation in total length L (mm) of *Sinanodonta woodiana* in the Konin heated lake system in the 1999–2002 (ICB – initial cooling basin)

Table 3. Morphometric parameters of *Sinanodonta woodiana* in the Konin heated lakes system. For study sites see Fig. 2

Site	Variability measure	Parameter											
		L	H	W	l	h	H/L	W/L	W/H	l/L	h/H	h/L	M [g]
		[mm]											
Ślesińskie Lake site 1 (N = 93)	min	64	32	17	25	35	0.50	0.27	0.53	0.27	1.00	0.54	18.5
	max	161	90	61	65	100	0.66	0.45	0.75	0.47	1.18	0.73	464.1
	$\bar{x}$	113.5	65.6	41.8	44.0	70.7	0.578	0.366	0.638	0.389	1.080	0.624	159.80
	sd	19.9	12.0	7.9	8.6	12.6	0.03	0.03	0.05	0.04	0.03	0.04	82.1
	ν	17.5	18.3	18.8	19.6	17.9	6.0	8.3	7.5	9.3	3.0	6.2	51.4
Licheńskie Lake site 5 (N = 258)	min	53	28	16	21	30	0.46	0.26	0.40	0.25	0.99	0.50	14.0
	max	151	96	60	62	99	0.72	0.48	0.84	0.50	1.33	0.77	388.2
	$\bar{x}$	107.7	61.5	39.4	39.7	66.7	0.571	0.365	0.642	0.370	1.086	0.619	144.28
	sd	17.1	10.8	7.2	7.1	11.2	0.04	0.03	0.06	0.04	0.04	0.04	64.0
	ν	15.9	17.5	18.2	17.8	16.9	7.1	9.2	8.7	11.3	3.9	6.3	45.5
Initial cooling reservoir discharge zone sites 7, 8 (N = 323)	min	42	26	12	14	23	0.43	0.25	0.44	0.21	0.68	0.42	5.2
	max	241	122	72	95	124	0.70	0.43	0.71	0.47	1.22	0.72	787.0
	$\bar{x}$	160.8	87.5	51.1	54.2	89.2	0.557	0.325	0.585	0.344	1.021	0.569	363.66
	sd	32.5	16.2	9.6	12.5	16.4	0.04	0.03	0.05	0.04	0.05	0.05	150.7
	ν	20.6	18.5	18.8	23.1	18.4	7.4	9.4	8.6	12.3	4.8	8.5	41.5
Initial cooling reservoir outflow zone site 6 (N = 51)	min	52	30	16	17	30	0.45	0.30	0.49	0.26	0.99	0.46	12.4
	max	155	87	60	36	95	0.77	0.53	0.88	0.33	1.14	0.84	329.5
	$\bar{x}$	96.0	56.9	37.9	28.6	59.7	0.593	0.392	0.663	0.299	1.049	0.622	108.84
	sd	20.7	12.1	8.8	5.5	12.7	0.05	0.04	0.07	0.02	0.03	0.06	65.3
	ν	21.0	20.9	23.1	19.1	21.3	8.0	11.3	10.8	6.6	3.3	8.9	56.4
Konin Power Plant intake canal site 10 (N = 35)	min	44	30	15	12	30	0.50	0.30	0.50	0.27	0.99	0.52	10.5
	max	133	83	52	39	89	0.68	0.50	0.84	0.33	1.12	0.71	257.6
	$\bar{x}$	103.5	62.3	39.3	30.8	66.0	0.603	0.379	0.631	0.294	1.059	0.638	140.83
	sd	20.5	13.0	8.8	6.3	13.9	0.05	0.04	0.06	0.02	0.03	0.05	69.0
	ν	19.8	20.9	22.3	20.5	21.1	7.5	11.6	9.8	5.9	2.9	7.7	47.8
Piotrkowicki Canal site 15 (N = 142)	min	51	41	20	18	41	0.47	0.28	0.49	0.25	1.01	0.50	22.0
	max	187	107	65	73	122	0.80	0.46	0.81	0.45	1.20	0.84	529.0
	$\bar{x}$	127.3	74.5	46.6	44.6	81.3	0.587	0.366	0.626	0.349	1.090	0.639	246.30
	sd	19.9	12.4	8.3	10.5	14.0	0.05	0.03	0.06	0.05	0.04	0.05	96.7
	ν	15.6	16.7	17.8	23.7	17.2	8.8	9.1	9.7	15.7	3.6	8.4	40.4
Licheńsko-Pątnowski Canal site 16 (N = 79)	min	46	53	33	18	56.7	0.50	0.31	0.55	0.28	0.99	0.53	86.0
	max	185	103	61	72	112	0.77	0.87	0.76	0.49	1.18	1.39	586.8
	$\bar{x}$	134.6	78.0	49.9	48.1	83.0	0.587	0.376	0.642	0.357	1.064	0.624	289.56
	sd	20.7	11.2	6.8	10.5	12.0	0.05	0.07	0.05	0.05	0.05	0.10	104.2
	ν	15.4	14.3	13.6	21.8	14.5	8.0	17.7	7.4	14.2	4.3	16.3	36.0
Warta-Gopło Canal site 17 (N = 251)	min	34	20	9	10	22	0.13	0.06	0.45	0.22	0.98	0.15	3.5
	max	200	103	65	78	108	0.68	0.50	0.90	0.50	1.20	0.74	572.2
	$\bar{x}$	134.9	72.2	46.0	46.5	77.6	0.541	0.345	0.638	0.346	1.076	0.574	239.34
	sd	20.1	11.9	7.5	11.0	12.9	0.05	0.04	0.05	0.07	0.04	0.06	100.2
	ν	14.9	16.5	16.3	23.7	16.6	9.9	11.2	8.3	19.7	3.6	9.8	40.5
Licheński Canal site 18 (N = 131)	min	35	22	4	12	22	0.46	0.03	0.06	0.32	0.91	0.47	30.0
	max	174	97	62	80	109	0.63	0.42	0.78	0.49	1.20	0.72	482
	$\bar{x}$	137.8	74.2	46.0	57.6	81.9	0.540	0.334	0.621	0.418	1.101	0.595	252.81
	sd	17.9	9.7	7.7	8.7	11.3	0.03	0.04	0.08	0.03	0.05	0.04	75.8
	ν	13.0	13.1	16.7	15.0	13.8	6.2	12.1	12.6	7.3	4.2	7.1	29.9
Konin Power Plant discharge canal site 19 (N = 143)	min	19	14	6	10	16	0.48	0.24	0.43	0.22	0.92	0.48	1.1
	max	185	102	61	77	117	0.74	0.41	0.76	0.53	1.22	0.84	497.9
	$\bar{x}$	140.9	77.9	46.1	45.5	81.0	0.551	0.327	0.592	0.323	1.040	0.578	264.17
	sd	25.4	13.9	8.5	11.4	15.3	0.04	0.03	0.06	0.05	0.05	0.05	101.3
	ν	18.0	17.9	18.5	25.1	18.9	7.2	7.7	9.7	16.6	5.2	9.0	36.6

$\bar{x}$ – mean value, SD – standard deviation, í – coefficient of variation, N – sample size

Table 4. Arrangement of increasing likelihood of shell morphometrics and wet weight of the clam *Sinanodonta woodiana* (mean values) at various study sites

Parameter	Sites										R^2
L	ICB2	KEPPic	LL	SL	PC	L-PC	W-GC	LC	KEPPdc	ICB1	95.3
	96.0^{a}	103.5^{b}	107.7^{c}	113.5^{d}	127.3^{e}	134.6^{f}	134.9^{f}	137.8^{g}	140.9^{h}	160.8^{i}	
H	ICB2	LL	KEPPic	SL	W-GC	LC	PC	KEPPdc	L-PC	ICB1	91.6
	56.9^{a}	61.5^{b}	62.3^{b}	65.6^{c}	72.2^{d}	74.2^{d}	74.5^{d}	77.9^{e}	78.0^{e}	87.5^{f}	
W	ICB2	KEPPic	LL	SL	W-GC	LC	KEPPdc	PC	L-PC	ICB1	84.4
	37.9^{a}	39.3^{a}	39.4^{a}	41.8^{b}	46.0^{c}	46.0^{c}	46.1^{c}	46.6^{c}	49.9^{d}	51.1^{d}	
l	ICB2	KEPPic	LL	SL	PC	KEPPdc	W-GC	L-PC	ICB1	LC	95.6
	28.6^{a}	30.8^{a}	39.7^{b}	44.0^{c}	44.6^{c}	45.4^{c}	46.5^{cd}	48.1^{d}	54.2^{e}	57.6^{f}	
h	ICB2	KEPPic	LL	SL	W-GC	KEPPdc	PC	LC	L-PC	ICB1	83.9
	59.7^{a}	66.0^{b}	66.7^{b}	70.7^{c}	77.6^{d}	81.0^{e}	81.3^{e}	81.9^{e}	83.0^{e}	89.2^{f}	
H/L	LC	W-GC	KEPPdc	ICB1	LL	SL	L-PC	PC	ICB2	KEPPic	64.3
	0.540^{a}	0.541^{a}	0.551^{a}	0.557^{ab}	0.571^{bc}	0.578^{c}	0.587^{c}	0.587^{c}	0.593^{c}	0.603^{d}	
W/L	ICB1	KEPPdc	LC	W-GC	LL	PC	SL	L-PC	KEPPic	ICB2	91.1
	0.325^{a}	0.327^{a}	0.334^{ab}	0.345^{b}	0.365^{c}	0.366^{c}	0.369^{c}	0.376^{c}	0.379^{c}	0.392^{d}	
W/H	ICB1	KEPPdc	LC	PC	KEPPic	W-GC	SL	LL	L-PC	ICB2	23.0
	0.585^{a}	0.592^{a}	0.621^{b}	0.626^{b}	0.631^{b}	0.638^{b}	0.639^{b}	0.642^{b}	0.642^{b}	0.663^{c}	
l/L	KEPPic	ICB2	KEPPdc	ICB1	W-GC	PC	L-PC	LL	SL	LC	8.8
	0.294^{a}	0.299^{a}	0.323^{b}	0.344^{c}	0.346^{c}	0.349^{c}	0.357^{cd}	0.370^{d}	0.389^{e}	0.418^{f}	
h/H	ICB1	KEPPdc	ICB2	KEPPic	L-PC	W-GC	SL	LL	PC	LC	61.1
	1.021^{a}	1.040^{b}	1.049^{bc}	1.059^{c}	1.064^{cd}	1.076^{de}	1.080^{de}	1.086^{e}	1.090^{e}	1.101^{e}	
M	ICB2	KEPPic	LL	SL	W-GC	PC	LC	KEPPdc	L-PC	ICB1	98.8
	108.8^{a}	140.83^{ab}	144.28^{ab}	159.80^{b}	239.3^{c}	246.3^{c}	252.8^{c}	264.17^{c}	289.56^{c}	363.66^{d}	

R^2 – coefficient of determination

*Identical indices indicate a significant probability between stations with regard to the analysed parameter (T-Tukey test, α=0.05).

**Abbreviations of study sites:

SL – Ślesińskie Lake (st. 1), LL – Licheńskie Lake (st. 5), ICB1 – reservoir of initial cooling – discharge zone (st. 7, 8), ICB2 – reservoir of initial cooling – outflow zone (st. 6), KEPPic – Konin Power Plant intake canal (st. 10), PC – Piotrkowicki Canal (15), L-PC – Licheńsko-Pątnowski Canal (st. 16), W-GC – Warta-Gopło Canal (st. 17), LC – Licheński Canal (18), KPPdc – Konin Power Plant discharge canal (20)

In general, with age the growth of shell length (L) intensified in comparison to that of height (H) and width (W), while the shell length (H/L) and width (W/L) coefficients tended to decrease. The variability coefficient of W/H indicated faster growth of width in relation to height in younger specimens. Growth in mature clams was primarily in shell length. There was not much variation (under 10%) in the shell shape coefficient at individual sites (H/L, W/L, W/H, h/H, h/L), with the exception of the l/L coefficient (Table 3).

The clams with the highest shell height coefficient H/L were found in the Konin power plant intake canal (mean 0.603), in the mid section and outflow zone of the initial cooling basin and in Lake Gosławskie (mean 0.593) (Table 3). Their shell height (H) was relatively large in comparison with the shell length (L). The lowest values of this coefficient were noted in clams from the warm Warta-Gopło and Licheński canals and discharge canals of both the Konin and Pątnów power plants (mean 0.540–0.551). The variation of this parameter between the sites was significant (Table 4).

The clams from the Piotrkowicki Canal and the Konin power plant intake canal had the highest h/L coefficient (0.639 and 0.638, respectively), while the lowest values (mean 0.569-0.595) were those for specimens from the warmest canals and the immediate vicinity of the water discharge into the initial cooling basin (Table 3). The posterior edge of the shell was clearly raised in the clams from the Piotrkowicki Canal and Lake Licheńskie and its canal; it was less pronounced in specimens from the immediate vicinity of the water discharge into the initial cooling basin. Variation in the h/H coefficient between the sites was significant.

The l/L coefficient, which describes the distance from the shell apex to the end of the wing, was the highest in the clams from the Licheński Canal (mean

0.418), and the lowest in clams occurring in the mid section and outflow zone of the initial cooling basin (mean 0.299) and in the Konin power plant intake canal (mean 0.249) (Table 3).

The shell coefficients W/L and W/H (Table 3 and 4) were the highest in clams from lakes Licheńskie and Pątnowskie and from the Licheńsko-Pątnowski, fish farm pond discharge, Konin power plant intake, and the outflow zone of the initial cooling basin. In relation to length (L) and height (H), the shell width was significant here. The lowest shell width coefficients were noted in the clams from the Konin power plant discharge canal and the immediate vicinity of the water discharge into the initial cooling basin.

Although *S. woodiana* from the Konin lake system exhibited a certain amount of variation in the shell shape, they differed significantly from the native unionid populations. They were also decidedly larger. The average shell length of *S. woodiana* was 120 mm. *Unio tumidus* and *U. pictorum*, which are indigenous to the Konin system, were on an average 60 mm long, *Anodonta anatina* and *A. cygnea* were 80 mm long. Single specimens of *S. woodiana* measured as much as 200 mm, and the largest recorded specimens were 234 and 241 mm.

No sexual dimorphism was observed in *S. woodiana*; nor did any of the morphometric parameters (L, H, W, H/L, W/L, W/H and M) differ significantly between males and females. The probability coefficient with regard to sex, study site, and their mutual interactions were insignificant in each case ($p > 0.05$).

SHELL SHAPE VARIATION

Two groups of *S. woodiana* which differed in their shell height were distinguished in the Konin lake system, based on the H/L coefficient. The lowest shells came from the warmest sites: Lake Licheńskie, Warta-Gopło, and Konin power plant discharge canals where the water flow exceeded 0.1 ms^{-1}. The highest clams occurred in the lentic zones of moderately heated waters, such as Lake Ślesińskie, the mid section and outflow zone of the initial cooling basin, and the Piotrkowicki, Licheńsko-Pątnowski and the cold Konin intake canals (Table 4).

Based on the width (W/L and W/H) coefficients, three types of shells were identified which differed significantly in their width. Clams with the narrowest shells came from the area of the warmest heated water discharge. The second group included clams from lakes Ślesińskie and Licheńskie and the Piotrkowicki, Konin power plant intake, and Licheński canals. The third group, which was the most convex, occupied the area of the initial cooling basin water outflow zone (Table 4).

The h/H coefficient, which describes the slope of the posterior edge of the clam (gentle or distinct), permitted singling out significantly, extremely varied clams, that occurred in the immediate vicinity of the discharge area of the initial cooling basin and specimens inhabiting Lake Licheńskie and the Piotrkowicki and Licheński canals (Table 4).

Analogously, five groups were distinguished based on the l/L coefficient. The clams from the Konin power plant intake canal and the mid section and outflow zone of the initial cooling basin differed most from the clams from the Licheński Canal (Table 4).

Clear morphological variation of the shells was not only visible among the various lakes and canals, it was also notable within the initial cooling basin of only 70 ha (Tables 3a, b, 4). The substrata, turbulence, and thermal regime differed between the immediate vicinity of the water discharge and the outflow zone of the initial cooling basin. Significant variations in the shell size, shape, and colour were observed in the clams from the immediate vicinity of the post-cooling water discharge (sites 7, 8) and from the zones farther away from this area (site 6) (Fig. 1). The clams from the discharge zone were decidedly larger than those inhabiting the farther reaches of the basin. Their mean shell length was 150 mm and the maximum length was 241 mm, while in the farther reaches of the basin the corresponding values were 100 and 155 mm. The shells of clams from the mid section and the outflow zone of the basin were the widest (W/L) and almost the highest (H/L), compared to all other clams of the system. The shells of clams from the immediate vicinity of the discharge were dark brown, while those from other zones of the basin were a light honey-brown colour.

WEIGHT VARIATION

The wet weight (including the shell[1]) of *S. woodiana* differed significantly between sites; the heaviest clams generally occurred in the warmest habitats that also had the fastest flow. The clams from the immediate vicinity of the post-cooling water discharge in the initial cooling basin were generally heavier (mean M 364 g) (Table 3). Somewhat lighter specimens (mean 240–290 g) occurred in the warm canals. The canals that carried water away from the fish farm ponds and Lake Gosławskie were inhabited by clams with the lowest weight (<100 g). The differences in the wet weight were confirmed with the T-Tukey test (Table 4). Weight differences were also observed between the age classes at monitored sites (Fig. 6). The annual weight increment also varied among sites; the mean for the whole population was approximately 100 g.

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[1] Water losses from the mantle cavity during wet weight measurements, which were conducted within 120 minutes of sampling, did not exceed 1.7%.

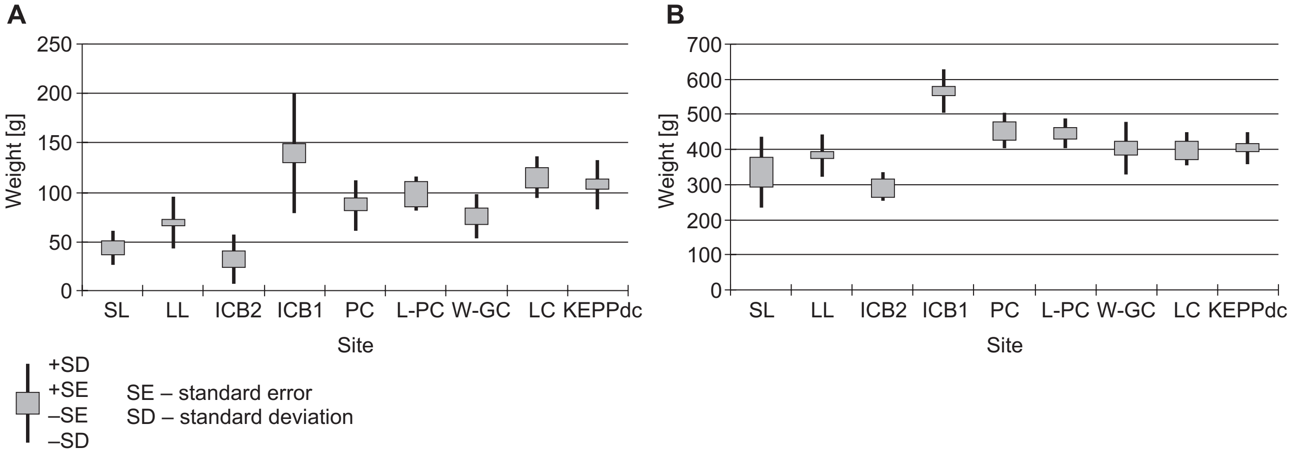

Fig. 6. Individual weight of selected *Sinanodonta woodiana* age groups – (A) two year, (B) six year, at sites with various habitat conditions (SL – Ślesińskie Lake, LL – Licheńskie Lake, ICB2 Cooling Reservoir – outflow zone, ICB1 Cooling Reservoir – discharge zone, PC – Piotrkowicki Canal, L-PC – Licheńsko-Pątnowski Canal, W-GC – Warta-Gopło Canal, LC – Licheński Canal, KEPPdc – Konin power plant discharge canal)

DISCUSSION

The results indicate that habitat has a significant effect on the shell shape variation of *S. woodiana*. Shell characters are the basic criteria, when identifying bivalves (Zhadin 1952, Kodolova & Logvinenko 1974, Arter 1989, Dyduch-Falniowska & Kozioł 1989, Aldridge 1999, Zettler 2000). The plasticity of the shell phenotype of *S. woodiana* is as large as in many other unionid species (Eagar 1978, Dudgeon & Morton 1983, Hinch et al. 1986, Kiss & Pekli 1988, Hanson et al. 1988, Bailey 1989, Green et al. 1989, Kiss 1992). This is reflected in the significant variation of the various habitats, in which the Konin system clams were able to form more or less dense populations. Morphological variation in clam shells was even discernable in the small initial cooling basin. The substrata, turbulence, and thermal regime differed in the water discharge and outflow zones of the initial cooling basin. Due to adapting their shell shape, the clams occurring here are able to function under varied environmental conditions.

Water turbulence can modify the size and shape of clam shells. Green et al. (1989) found that, when exposed to water flow, *Elliptio complanata* was longer and wider. The clams in the strong water flow of the heated Konin canals and in the immediate vicinity of the post-cooling water discharge into the initial cooling basin were longer, lower, and less convex (narrower). Specimens from the remaining sites were shorter, had a more pronounced posterior ridge, and, in the mid section, were strongly convex.

The shell colour of *S. woodiana* matched that of the substratum; this is a fairly common phenomenon in aquatic and terrestrial molluscs. Byers (1990) believes that polymorphic shell color in molluscs is a typical phenomenon effected by the interaction of many environmental factors.

The posterior lengthening of the shell, with the simultaneous shortening and thickening of the anterior part permits *S. woodiana* to burrow into muddy and sandy substrata. The anchoring in these clams is effected by the relatively large foot, since the species lacks mobile siphons and the shells have a rather smooth surface. In many clam species that burrow in the substratum, or at least in members of the genera *Mya*, *Macoma*, and *Lutraria*, these physical characteristics are of primary significance (Falniowski 2001).

Most clams of the genus *Anodonta* (Piechocki & Dyduch-Falniowska 1993) do not exhibit sexual dimorphism. Haukioja & Hakala (1978) and Dudgeon & Morton (1983) maintain that females may be more convex and slightly larger than males of the same age class, as a result of having larger gonads. The Chinese clam from the Konin system showed no significant difference in the morphometric parameters of shells of specimens of both sexes.

In the Konin lake system *S. woodiana* reached considerable shell sizes, with the largest examples (above 200 mm, with record sizes of 230–240 mm) noted in the warmest, lotic habitats. Larger individuals of this species, measuring 270 mm (Girardi & Ledoux 1989), 266 mm (Djajasasmita 1982), and 251 mm (Kiss 1995) were found in France, Java, and Hungary, respectively.

The growth of the Chinese clam in the Konin system was more intense than in the same species inhabiting aquatic ecosystems in Hungary (Kiss 1995). In comparison with other unionids, this difference was much more significant (Lewandowski & Stańczykowska 1975, Alimov 1981, Abraszewska-Kowalczyk 2002, Kraszewski unpublished.)

CONCLUSIONS

In the Konin heated lake system *Sinanodonta woodiana* exhibits a significant variation in shell shape, as a result of the high heterogeneity of the habitats. The shell morphology, size, and colour are affected by environmental factors, the most important of which are water temperature and flow rate and the character of the substratum. The clams in the warmest and fastest flowing canal waters have the lowest shells, while those in the lentic zones of the moderately heated lakes – the highest. The clams in the warmest habitats have flattened shells. Habitat conditions also have a significant effect on the growth, which is reflected in the significant differences among the linear measurements of the shells of clams from habitats of different character.

REFERENCES

Abraszewska-Kowalczyk A. 2002. Unionid bivalves of the Pilica river catchment area. Folia Malacol. 10: 99–173.

Aldridge D. C. 1999. The morphology, growth and reproduction of *Unionidae* in fenland waterway. J. Moll. Stud. 65: 47–60.

Alimov A. F. 1981. Funktsyonalnaya ekologia presnovodnykh dvustvorchatykh mollyuskov. Nauka, Leningrad.

Arter H. 1989. Effect of eutrophication on species composition and growth of freshwater mussels (Mollusca, Unionidae) in Lake Hallwil (Aargau, Switzerland). Aquat. Sci. 51: 87–99.

Bailey R. C. 1989. Habitat selection by freshwater mussel: an experimental test. Malacologia 31: 205–210.

Byers B. A. 1990. Shell colour polymorphism associated with substrate colour in the intertidal snail *Littorina saxatilis* Olivi (Prosobranchia: Littorinidae). Biol. J. Linn. Soc. 40: 3–10.

Djajasasmita M. 1982. The occurrence of *Anodonta woodiana* Lea 1837 in Indonesia (Pelecypoda: Unionidae). Veliger 25: 175.

Dudgeon D., Morton B. 1983. The population dynamics and sexual strategy of *Anodonta woodiana* (Bivalvia, Unionacea) in Plover Cove Reservoir, Hong Kong. J. Zool. London 201: 161–183.

Dyduch-Falniowska A., Kozioł R. 1989. Anatomical and conchological characters in the systematics of the Unionidae of Poland (Bivalvia, Eulamellibranchiata). Malak. Abh. 14: 35–52.

Eagar R. M. C. 1978. Shape and function of the shell: a comparison of some living and fossil bivalve molluscs. Biol. Rev. 53: 169–210.

Falniowski A. 2001. Direct and indirect mollusc evolution. Polish Academy of Arts and Sciences. Thesis from the Department of Natural History, Volume 1, 378 pp.

Girardi H., Ledoux J-C. 1989. Présence d'*Anodonta woodiana* (Lea) en France (Mollusques, Lamellibranches, Unionidae). Bull. Mens Soc. Lim. Lyon 58: 286–291.

Green R. H., Bailey R. C., Hinch S. G., Metcalfe J. L., Young V. H. 1989. Use of freswater mussels (Bivalvia: Unionidae) to monitor the nearshore environment of lakes. J. Great Lakes Res. 15: 635–644.

Hanson J. M., Mackay W. C., Prepas E. E. 1988. The effects of water depth and density on the growth of a unionid clam. Fresh. Biol. 19: 345–355.

Haukioja E., Hakala T. 1978. Measuring growth from shell rings in populations of *Anodonta piscinalis* (Pelecypoda, Unionidae). Ann. Zool. Fenn. 15: 60–65.

Hillbricht-Ilkowska A., Zdanowski B. 1978. Effect of thermal effluents and retention time of lake functioning and ecological efficiencies in plankton communities. Int. Rev. Hydrobiol. 63: 609–617.

Hillbricht-Ilkowska A., Zdanowski B. 1988. Main changes in the Konin lake system (Poland) under the effect of heated-water discharge pollution and fishery. Ekol. Pol. 36: 23–45.

Hinch S. G., Bailey R. C., Green R. H. 1986. Growth of *Lampsilis radiata* (Bivalvia: Unionidae) in sand and mud: a reciprocal transplant experiment. Can. J. Fish. Aquat. Sci. 43: 548–552.

Kiss A. 1992. *Anodonta woodiana woodiana* (Lea 1834) (Bivalvia: Unionacea) in Hungary. Atti Congresso di Parma, 11–13 ottobre 1990, Lavori S. I. M. Parma 24: 171–176.

Kiss A. 1995. The propagation, growth and biomass of the chinese huge mussel (*Anodonta woodiana woodiana* Lea, 1834) in Hungary. University of Agricultural Sciences of Godollo. Hungary. Privat Edition, Second Ed.

Kiss A., Pekli J. 1988. On the growth rate of *Anodonta woodiana woodiana* (Lea 1834) (Bivalvia: Unionacea). Bull. Agric. Sci. 1: 119–124.

Kodolova O. P., Logvinenko B. M. 1974. Sravnenye raznykh populatsiy dvustvorchatykh mollyuskov roda *Anodonta* (Unionidae) po sistemam miogenov i morfologii rakovin. Zool. Zh., 53: 531–545.

Kondracki J. 1998. Polish Regional Geography. Greater Poland Lakeland, pp. 124–152.

Korycka A., Zdanowski B. 1976. Impact of the discharge of heated waters on the chemicals in the waters of the Konin lakes system. Rocz. Nauk. Rol., Seria H 97: 89–107.

Kraszewski A., Zdanowski B. 2001. The distribution and abundance of the chinese mussel *Anodonta woodiana* (Lea, 1834) in the heated Konin lakes. Arch. Pol. Fish. 9: 253–265.

Lewandowski K., Stańczykowska A. 1975. The occurrence and role of bivalves of the family Unionidae in Mikołajskie Lake. Ekol. Pol. 23: 317–334.

Piechocki A., Dyduch-Falniowska A. 1993. Mollusca (Bivalvia). Fauna Słodkowodna Polski 7A, PWN Warszawa.

PROTASOV A. A., STARODUB K. D., AFANASJEV S. A. 1982. Vodolaznyi metod issledovanya presnovodnogo perifitona. Gidrobiol. Zh. 18: 91–93.

PROTASOV A. A., AFANASJEV S. A., ZDANOWSKI B. 1993. Natural systems for self-cleaning the waters of the Konin lakes. Kom. Ryb. 6: 6–9.

ZDANOWSKI B. 1989. Itogi mnogoletnikh nabludeniy za izmenenem ekosistem ozer pod vodeystvem sbrosnykh vod. GRES. Sb. Nauch. Trudov. GOSNIORCH, Leningrad 299: 3–22.

ZDANOWSKI B. 1994. Ecological disturbances in heated Konin lakes. Characteristics of heated Konin lakes, pollution, sources, main results and conclusions. Arch. Ryb. Pol. 2: 139–160.

ZDANOWSKI B., PROTASOV A. A, AFANASJEV S. A, SINICYNA O. 1996. Strukturnyje i funktsionalnyje osobennosti gruppirovok zoobentosa i zooperifitona koninskikh ozer. Gidrobiol. Zh. 32: 36–48.

ZETTLER M. L. 2000. Weitere Bemerkungen zur Morphologie von *Unio crassus* Philipsson 1788 aus dem nordeuropäischen Vereisungsgebiet (Bivalvia: Unionidae). Malakol. Abh. 20: 73–78.

ZHADIN V. I. 1952. Mollyuski presnykh i solonovatykh vod CCCP. Akademia Nauk SSSR, Moskva–Leningrad.

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