HABITAT PREFERENCES OF SWAN MUSSEL *Anodonta cygnea* (Linnaeus 1758) (BIVALVIA, *Unionidae*) IN RELATION TO STRUCTURE AND SUCCESSIONAL STAGE OF FLOODPLAIN WATERBODIES

KATARZYNA ZAJĄC

Institute of Nature Conservation, Polish Academy of Sciences, Mickiewicza 33, 31-120 Kraków, Poland

Abstract

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The habitat requirements of swan mussel *Anodonta cygnea* L. were studied in water bodies on the floodplain of the Nida river (Southern Poland). Swan mussel showed preferences neither for the geomorphologic types of water bodies nor for natural vs. anthropogenic site origin. It occurred more frequently in wide ponds, with less complicated bank line. Traits of water bodies that were linked with presence of swan mussel correlated also with concentration of dissolved oxygen. Swan mussel avoided silted water bodies and those with high proportion of surface overgrown with floating vegetation. It showed co-occurrence with plants from genus *Ceratophyllum* L. and *Hydrocharis* L. It was concluded that preference of the species for larger water bodies, of simpler shape and at early successional stages was related to high oxygen demand in this species. The functioning of natural river valley versus regulated river were discussed in relation to occurrence of large mussel species.

Introduction

The mosaic structure and dynamic nature of river systems influence their biodiversity patterns. Unmanaged rivers and their floodplains can encompass a great variety of habitats. They have diverse geomorphologic structure with pools, bars, riffles, secondary channels, backwaters, oxbows and marshes, which results in a mosaic of habitat patches and successional stages. Much of the biodiversity associated with river floodplains is attributable to this heterogeneity at the habitat scale.

In Europe massive river regulation works were completed prior to the twentieth century. The engineering works on the rivers (aimed at reducing flooding or at land reclamation) resulted in the reduced ability of river valleys to carry out their natural functions (flooding, sediment and nutrients storage, relief shaping). Amongst the most pronounced effects of regulations on floodplain river is stopping erosional/deposition processes related to lateral migration of the river bed, and in the consequential decrease of the spatiotemporal heterogeneity (e.g. acceleration of the terrestralization of extant waterbodies) which ultimately reduces the wildlife value of river valleys (Ward, 1998).

A group of animals, which is severely threatened by anthropogenic changes in river valleys, are mussels – organisms whose populations very frequently represent the majority of the total biomass in many aquatic ecosystems (Negus, 1966). Mussel populations are rapidly declining in areas of large species richness, e.g. in North America; moreover they have economical value (Neves, 1999; Cummings, Mayer, 1992). IUCN Red Data List (Hilton-Taylor, 2000) comprises almost 2/3 of unionid species of this continent. Among globally threatened molluscs, family *Unionidae* has the largest number of threatened species (Kay, 1995). In Europe also many of the species of this family are included in Red Data Lists (Dyduch-Falniowska, 1992).

The central issue both for conservation of prospering mussel population and for restoration of declining populations is to ascertain their habitat requirements against the background of ecosystem functioning. Despite much research, little is known about the factors which determine mussel distribution (Aldridge, 2000). According to earlier studies their assemblages in rivers were related to current speed and character of sediments, which are determined by the size of river (or other water body), diversity of bottom sediments (Hartman, 1972) and geological structure of the area (Strayer, 1983). The impact of abiotic factors on mussels from the family *Unionidae* was analysed by Holland-Bartels (1990). These studies attempted to describe the habitat requirements of mussels on a quite detailed level, which does not seem to be a very promising approach (Aldridge, 2000). Until now no study has attempted to correlate habitat requirements of mussels with river valley spatiotemporal heterogeneity, e.g. to the types of geomorphologic structures preferred by bivalves, influence of successional processes on those structures and mechanism related to these processes. This knowledge is also important in practice. It should be known which elements of floodplain should be preserved for bivalve protection and/or which should be reconstructed in river restoration programmes and which way they should function.

An influence of habitat succession on mussel's occurrence is also an interesting problem. Does succession promote saving the most valuable species of benthofauna, or does successional progress change the habitat of mussels, resulting in their elimination from the site? This last issue is especially important in the case of regulated rivers, because halting erosion/deposition processes related to lateral migration of the riverbed results in irreversible consequences for succession.

The aim of this research was to study the relationship between the occurrence of swan mussel *Anodonta cygnea* (Linnaeus 1758), and geomorphology and/or successional stage of small water bodies occurring on the floodplain of seminatural, lowland Nida river.

Material and methods

The study area, covering ca 30 km² (Fig.1) was located in the middle part of the Nida river, a tributary of the Vistula (southern Poland), near Pińczów (50°37'30" - 50°28'00" N, 20°27'30" - 20°33'00" E). Nida river valley is flat and 2-6 km wide. It is covered with alluvial sandy soils, only some small areas are covered with peat. The slope of the valley is small – over a distance of 40 km the difference in altitude is only 14.6 m (Kostrowicki, Solon, 1994). The river is shallow, water depth in the main river rarely exceeding 2 m. The width of the river bottom changes from 26 m near Motkowice village to 40 m near Pińczów. The study area covers the valley both with meandering and anastomosing river channel. During the last 150 years the mean meander radius reached ca 250 m, thus the zone of the lateral migration of bed was 500 m width, and the meandering degree reached ca 1.50.

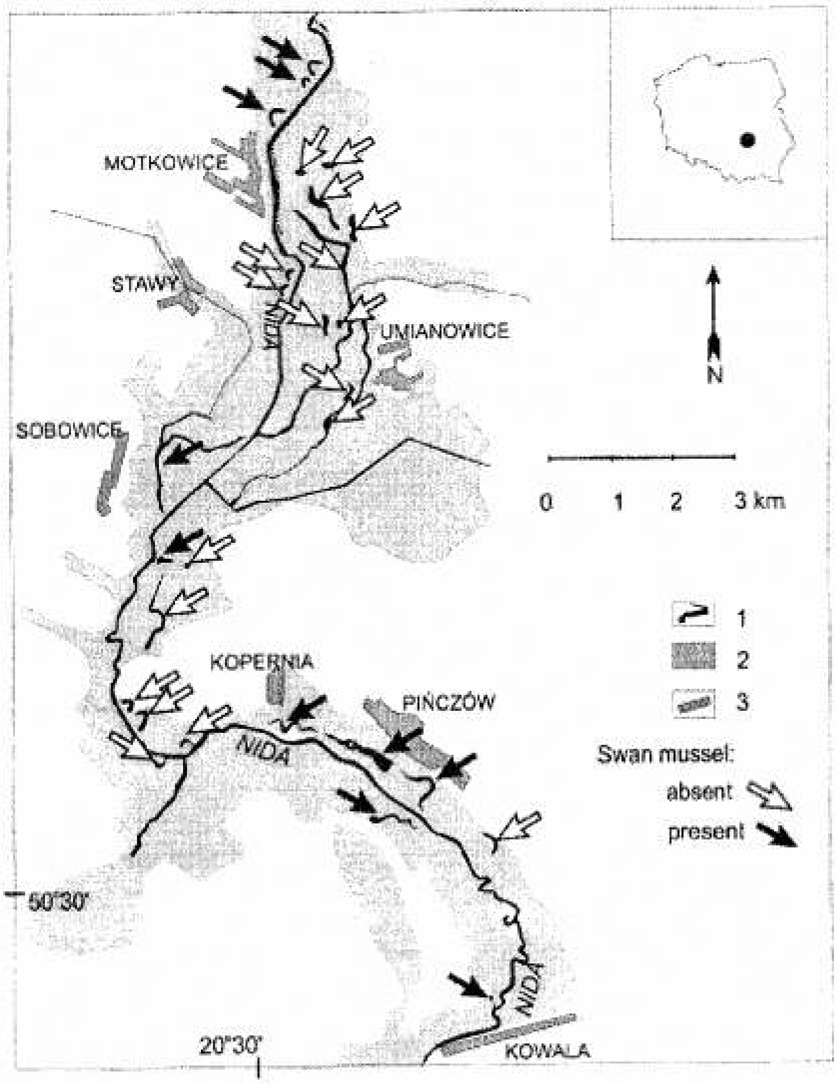

Fig. 1. Map of the study area. White arrows indicate water bodies without swan mussel, black arrows indicate water bodies inhabited by swan mussel; 1 – water bodies, 2 – floodplain, 3–settlements.

The majority of the floodplain is covered with meadows, with smaller areas of pastures or natural wetlands. In the 1980's partial regulation of the river course was enforced on the Motkowice-Pińczów section (Korzeniak et al., 1995; Fig. 1). Modifications comprised partial canalisation of the riverbed while preserving connection between some anostomosing arms of the river and one or two side embankments.

The study was done in 1997-1999. It was restricted to the waterbodies on the floodplain, as the main riverbed is the subject of a separate study. Water bodies on the studied area of floodplain were included in the study if they met at least minimally the habitat requirements of swan mussel (Piechocki, Dyduch-Falniowska, 1993). Water bodies were classified into 5 geomorphologic categories (Fig. 2).

Samples of the bottom were haul every 10 m of water body bank using nylon mesh dredge (mesh size: 2.5 mm; mouth size 0.4 m) from different depths (dependent on the local relief). Each sample was carefully checked for the presence of the mussels. Using material from these samples, the range of silt of the bottom was drawn on the map. At the same time water surface area covered by plants was mapped. Percentages of the water body surface area overgrown by plants as well as the percentage of the water body bottom covered by silt were estimated from the field maps using GIS.

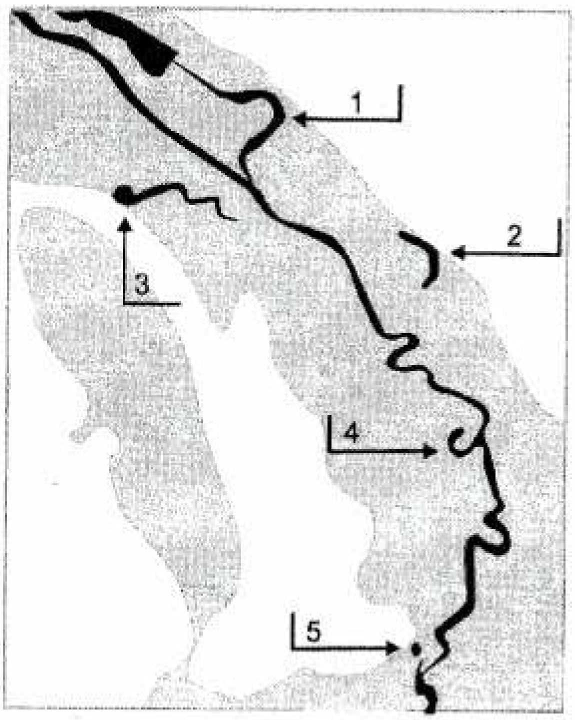

Fig. 2. Water bodies classification. 1 – old river side-arms with flow, 2 – oxbows, 3 – river side-arms without flow, 4 – backwaters, 5 – water "eyes".

For each water body dimensions were measured and the shape was described. Mean depth was measured directly in the field, whereas length, width, surface area and shoreline length were measured using the GIS "Arc-Info" package, using a digitised map of the area. The length was measured as the shortest distance between the two most distant points of the shoreline draw along a line within the limits of the water body. The width is the longest distance between two banks of the water body perpendicular to length line. An index of bank line complexity (*C*) was calculated as the ratio of water body perimeter to surface area. Water bodies with swan mussel present were compared to those without this species, with regard to each of the above mentioned traits. In most cases nonparametric statistical tests were used throughout the paper because the distribution of analysed data was usually significantly different from normality.

The stage of the succession of the water body was determined on the basis of degree siltation and relative area of the water surface covered with vegetation. Three categories of siltation were distinguished (Stern, 1983): silted bottom - all area of bottom covered with silt; silted-sandy bottom – the deepest parts of the water body covered with silt, at least 1/4 of the bottom area covered with sand; sandy bottom – over 1/4 of the bottom covered with sand, without silt. During the inspection of the water body all plant species within it and on the banks were noted, in order to determine plant species occurring with swan mussel. Water samples were collected in autumn 1998 and dissolved oxygen concentration was measured in the lab of Karol Starmach Institute of Freshwater Biology of Polish Academy of Sciences, using methods described by Hermanowicz et al. (1976).

Results

Among 28 water bodies studied, river regulation works (cut meanders, stabilised banks of side arms of the river) influenced 12, whereas the rest retain their natural character. Swan mussels were found in 10 (36%) out of the 28 studied water bodies. They occurred most frequently in old river side arms, especially in those still with slight water flow. If swan mussel shows no preference towards any of geomorphologic category of water bodies then the number of occupied water bodies within each geomorphologic category should be proportional to the number of all water bodies within each of the same geomorphologic categories. However, the frequency distribution of water bodies occupied by swan mussel in each geomorphologic category (observed frequency) did not differ significantly compared to the frequency distribution of all water bodies in each geomorphologic category, present on the study area (assumed as expected frequency; goodness of fit test, $\chi^2 = 3.06$, df = 4, p = 0.55).

Studied water bodies were diverse in size and shape. The smallest surface area of water body was 591.2 m^2 and the largest one was 77732.9 m^2. The majority of them was very

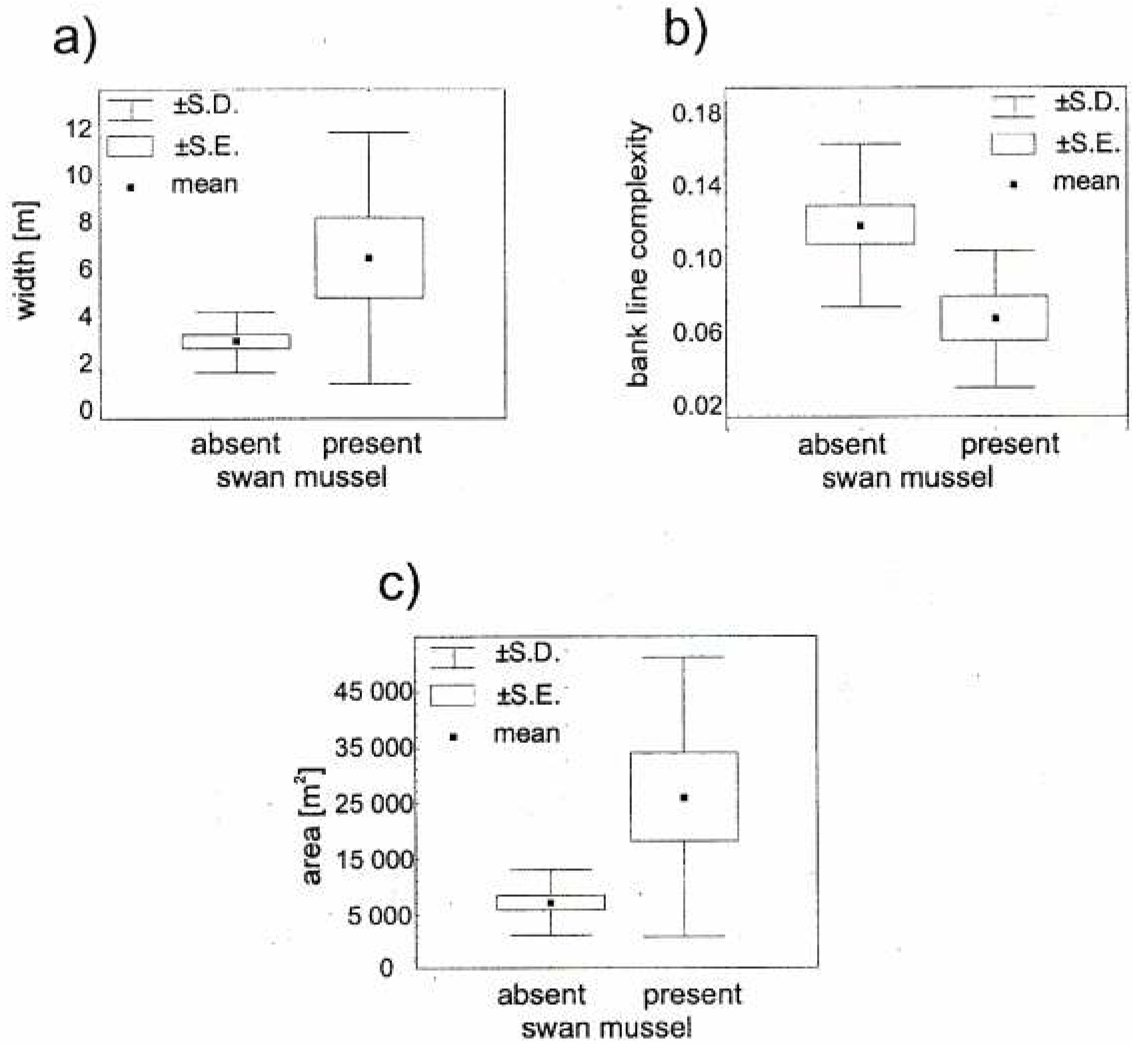

Fig. 3. Occurrence of swan mussel versus various to geomorphologic traits of water bodies: a) width, b) index of bank line complexity, c) surface area.

small (surface areas of 21 bodies were less than the average = 15103.43 m², which was the mean value for all of them).

Presence of swan mussel was correlated neither with water body length (Mann-Withney test, U = 65, n = 28, p = 0.23) nor depth (one way ANOVA, F(1, 26) = 0.20, p = 0.66). Water bodies occupied by swan mussels were significantly wider (Mann-Withney test, U = 42, n = 28, p = 0.021, Fig. 3a) and more compact, with shorter, less complicated bank lines - the difference in the index of bank line complexity (*C*) was highly significant (one way ANOVA, F(1, 26) = 11.02, p = 0.003, Fig. 3b). The difference was even more distinct when controlled for the influence of water body geomorphologic category (two way ANOVA, F(2, 17) = 22.3, p = 0.0002). The difference in surface area between occupied and unoccupied water bodies was close to statistical significance (Mann-Withney test, U = 50, n = 28, p = 0.055; Fig. 3c).

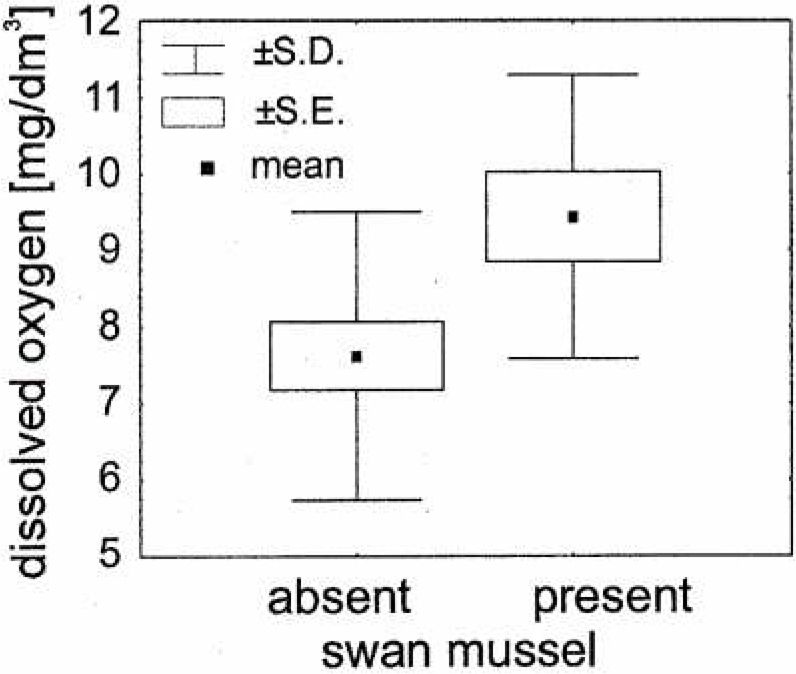

Fig. 4. Difference in concentration of dissolved oxygen between water bodies occupied and unoccupied by swan mussel.

Water bodies of anthropogenic character were significantly shallower than natural ones (Mann-Withney test, $U = 47$, $n = 28$, $p = 0.023$). But no differences were found between water bodies occupied and unoccupied by swan mussel with regard to anthropogenic or natural character of water body (Fisher exact test, $p = 0.139$).

Swan mussels occur more frequently on sandy bottoms. Their occurrence differs significantly between water bodies with silt bottom type and those of silt-sand type (Fisher exact test, two-tailed, $p = 0.001$). There were no significant differences between water bodies of sand bottom type and those of silt-sand type (Fisher exact test, two-tailed, $p = 0.99$), which justifies combining these two types of water bodies into one category. The comparison of this combined category with water bodies of silt bottom type gives a highly significant difference (Fisher exact test, one-tailed, $p = 0.0003$).

Water bodies occupied by swan mussel have significantly higher concentrations of dissolved oxygen (one way ANOVA, $F (1, 26) = 6.05$, $p = 0.027$; Fig. 4). There were significant correlations between the concentration of dissolved oxygen and the surface area of water and the index of bank line complexity – water bodies with larger surfaces and less

Table 1. Correlation between dissolved oxygen concentration and traits of water bodies morphology (N = 28)

Water body trait	r	P
width	0.35	0.067~
surface area	0.47	0.012*
depth	-0.23	0.237
length	0.32	0.095~
shoreline length	0.32	0.099~
index of the bank line complexity	-0.57	0.002**

~ $0.05 < p < 0.1$, * $p < 0.05$, ** $p < 0.01$

complicated bank line were better oxygenated (Table 1). Dissolved oxygen concentrations were significantly lower in water bodies of silt bottom type than in joined category of sand or silt-sand bottom types (one way ANOVA, $F(1, 26) = 4.38$, $p = 0.046$).

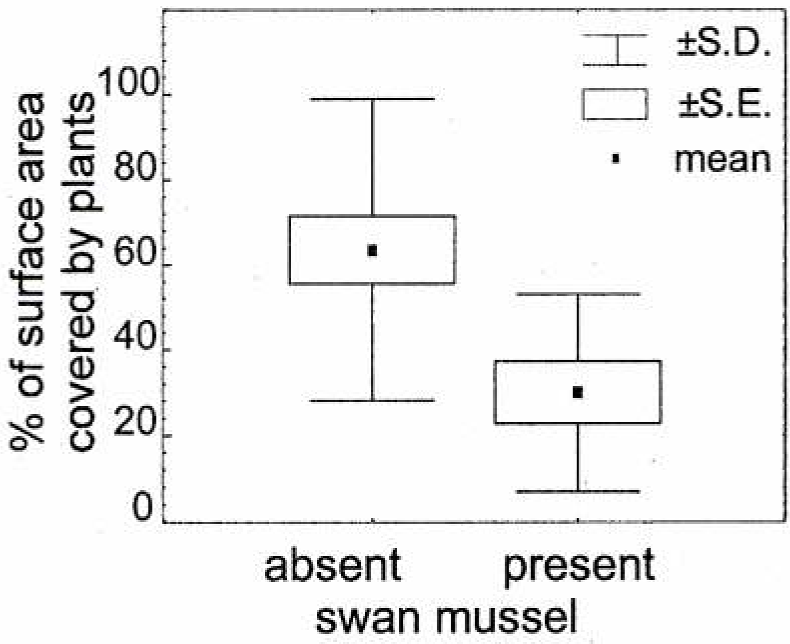

Fig. 5. Occurrence of swan mussel versus various successional trait of water body measured as % of surface area covered by plant.

Swan mussel occurs in water bodies with surfaces significantly less covered by floating vegetation (mean 30% of surface area) than unoccupied ones (mean 63.5%; mainly covered by *Lemna* L. sp., but also *Nuphar lutea* (L.) S i b t h. & S m.; one way ANOVA, $F(1, 28) = 7.32$; $p = 0.011$; Fig. 5). The area of water surface covered by floating vegetation was negatively correlated with

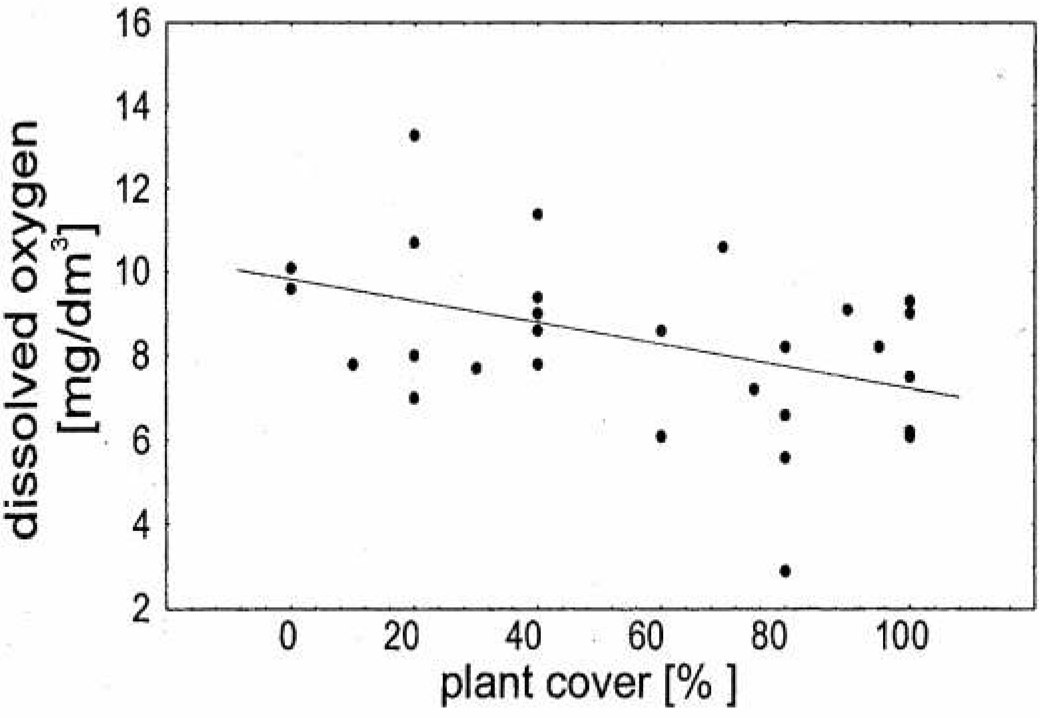

Fig. 6. Relation between water surface plant cover and dissolved oxygen concentration.

concentration of dissolved oxygen ($r = -0.42$, $N=29$, $p=0.027$, Fig. 6), so more overgrown waters had lower concentrations of dissolved oxygen.

Water bodies with swan mussels were more frequently occupied by plants belonging to *Ceratophyllum* (Fisher exact test, one-tailed, $p = 0.045$), and *Hydrocharis* (Fisher exact test, one-tailed, $p = 0.024$). *Ceratophyllum* grows in water bodies with higher concentration of dissolved oxygen (one way ANOVA, $F(1, 26) = 6.7$, $p = 0.016$), whereas in the case of *Hydrocharis* there was no significant relation between its occurrence and oxygen concentration (one way ANOVA, $F(1, 26) = 0.43$, $p = 0.5$).

Discussion and conclusions

The preference of swan mussels for ponds free from floating vegetation with low silt is related to water oxygen saturation. Swan mussels were found more frequently in water bodies characterised by high concentration of dissolved oxygen. Also swan mussel occurrence is related to the factors, that were also found to be correlated with high dissolved oxygen concentrations. The area of the water body and degree of shore line complexity show respectively positive and negative relation to oxygen concentration and the mussel's occurrence. Water bodies, which are overgrown with floating vegetation, or highly silted (traits related to later successional stage of the floodplain water body), have lower concentrations of oxygen in their water and therefore swan mussels avoid such places. By implication swan mussels prefer earlier successional stages of floodplain waterbodies.

Concentration of dissolved oxygen in the water depends primarily on the size of diffusion zone of this gas between air and surface of water (Naiman, Bilby, 1998), which explains the relation between size and shape of the waterbody and oxygen concentration. Large, compact surface area of open water, without diversified shoreline is maximally exposed to oxygen absorption. The negative relation of oxygen concentration to shore line complexity and area overgrown with floating vegetation may be easily explained by the reduced area for gas exchange. Floating vegetation decreases the area of water/air contact and its development is promoted by complicated shore line – on large open areas of water usually the wind pushes floating vegetation to one of the banks, whereas bays, side channels etc. usually protect floating vegetation against wind, thus promoting its development. Also, dissolved oxygen concentration depends on water surface turbulence which is greater on large areas of open water, than in bays.

Swan mussels are usually absent in highly silted water bodies, and this may also be related to oxygen concentration. Silted pond, in later stages of natural succession, are nutrient-enriched and they contain a large amounts of chemically active organic matter. The decomposition processes of such amounts of organic matter not only need and absorb a large amounts of dissolved oxygen, but also produce a number of deleterious chemical substances, negatively affecting all benthofauna (Allen, 1995; Naiman, Bilby, 1998).

Swan mussel is one of the largest freshwater mussels occurring in the northern Palaearctic, therefore its metabolism requires large amounts of oxygen, thus, its habitat choice should be oriented on high oxygen concentrations. Nida river, on whose floodplain the studied waterbodies occurred, has the warmest waters in Poland (Kostrowicki, Solon, 1994). Also the whole region is characterised by an extremely sunny and warm climate. Swan mussels live here in small, shallow ponds, which warm up very quickly, decreasing oxygen solubility (Allen, 1995). As in other *Unionidae*, swan mussels increase body temperature and metabolism with rising ambient temperature, causing higher oxygen demand. This mechanism was described previously for other unionids: *Unio tumidus* Philipsson 1788 (Tudorancea, Florescu, 1968), *U. mancus* Lamarck 1819 and *Anodonta cygnea* L. too (Ravera, Sprocati, 1997). Thus, swan mussel preference for well-oxygenated waters might be a consequence of their fast growth and large body size, and at the same time a serious constraint with regard to number of water bodies that can be occupied.

Plants, which co-occur with swan mussel (*Ceratophyllum* and *Hydrocharis*), are also related to well oxygenated ponds in early successional stages. These species could be good indicators of swan mussel waterbody quality, especially useful and important for restitution or reintroduction programmes.

Although swan mussel current habitat is continuously changing through natural succession into an unsuitable one, the probability of colonising new ones depends on the geological activity of the riverbed, which is less predictable. In natural river ecosystem the negative influence of natural succession on large mussel populations is compensated for by stable, permanent creation of new water bodies. Erosion and deposition processes related to lateral migration of the river bed guarantee creation of new oxbows, old river side arms in the same time in which natural succession eliminates the old ones. The probability of colonising new sites also depends on the other main process in rivers – flooding. In such conditions the optimal life strategy is to produce enormous quantities of progeny, which attached to effective vectors (fish) have a high probability of colonising, together with flood, any new water body, created on the floodplain.

River regulation works stop processes, which produce new, not colonised water bodies, suitable for swan mussel. It happens through stopping erosion/deposition processes related to lateral migration of the riverbed. Even if the floodplain containing small waterbodies is not destroyed, successional processes in waterbodies will eliminate mussels occurring there. River flow management eliminates also seasonal floods, stopping the migration and colonisation of habitats by glochidia, attached to fishes penetrating the whole of flooded area. Additionally, waterbodies separated from the main river channel by river regulation works are usually much shallower, which implies that succession acts faster within them. Thus even partial regulation of the river valley (which sometimes is proposed on areas of high natural value, as in the case of the study site), is also deleterious for the mussel fauna and finally leads to its extinction.

Thus, river regulation works eliminate the main functions of the river valley ecosystem, which guarantee saving species of fauna, characterised by life history traits similar to these of large mussels – enormous fecundity and large probability of colonisation of new sites. It is worth of notice, that minimising of this two most important river functions – (1) lateral migration of the bed, creating new water bodies and (2) seasonal floods – is a main goal of river training works. The first is related to land reclamation demands of local communities, the latter with their security. Both aims can be reached in other ways, without irreversible change habitat, causing extinction not only swan mussel but many other organisms.

Translated by the author

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Zajac K.: **Stanovište druhu** *Anodonta cygnea* (L i n n a e u s 1758) **vo vzťahu k štruktúre a sukcesnému štádiu lužných vodných telies.**

Požiadavky na stanovište u *Anodonta cygnea* L. sme skúmali na lužnom vodnom telese rieky Nida (južné Poľsko). Tento druh neuprednostňoval žiadny geomorfologický typ vodného telesa, ani stanovište prírodného alebo antropogenického pôvodu. Častejšie sa objavoval v rybníkoch s jednoduchšími brehovými líniami. Charakter vodných telies, ktorých spájala prítomnosť *Anodonta cygnea* L. korelovali s koncentráciou rozpustného kyslíka. Výhybali sa nánosom a vodným telesám, ktorých hladina bola pokrytá plávajúcou vegetáciou. Ukázalo sa, že dobre spolunažívajú s rastlinami rodu *Ceratophyllum* L. a *Hydrocharis* L. Skonštatovali sme, že uprednostňovanie veľkých vodných telies jednoduchého tvaru a v rannom sukcesnom štádiu súvisí s ich vysokou požiadavkou na kyslík. Význam prírodného riečneho údolia versus regulovaná rieka sme analyzovali z hľadiska výskytu druhov veľkých mušlí.