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THE CONSEQUENCES OF WATER RELEASE FROM A DAM RESERVOIR FOR FRESHWATER MUSSEL SURVIVAL: RECOMMENDATIONS FOR IMPROVED MANAGEMENT

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Abstract

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Dam reservoirs may play an important role in threatened freshwater mussel conservation. However, the restoration works on a dam and their consequences can threaten whole mussel populations. This study investigates the consequences of water release in the Czorsztyn Reservoir in order to improve management of dam reservoirs. The analysis shows that the reservoir's water releases caused massive death of freshwater mussels. The main threat for mussel survival was probably flat slopes that disturbed both their ability to perceive slope gradient and the possibility to escape. In order to decrease the losses of freshwater mussel populations, it is necessary to remodel a part of the reservoir bowl's shore and to create a *refugium* for the mussels. If terracing across the slopes is necessary, the steps should not be entirely plain, but tilted towards the water.

Key words: reservoir management, *Unionidae*, *Anodonta anatina*, mortality, mussel movements

Introduction

The freshwater mussel family *Unionidae* is listed as globally endangered (IUCN, 2007). Mussels are suspension feeders and filter water very effectively, thus increasing water clarity, which is essential for the protection of water quality in water supply reservoirs (Piechocki, Dyduch-Falniowska, 1993). On the other hand, dam reservoirs may play an important role in conservation of this taxon. Some older reservoirs in Poland, like Goczałkowicki, Sulejowski, Rożnowski and Zegrzyński, are inhabited by unionids endangered in this part of Europe (Zając, 2004). One of the biggest and not fully recognized threats for populations in reservoirs is water release, which can cause mussel extinction.

Although release of reservoir water is rarely conducted, it is essential for proper operation. Water level in the Czorsztyn Reservoir was reduced to a minimal water lifting level after 10 years of exploitation because of maintenance work on the dam. It created an opportunity to carry out observations on dead mussels on the reservoir shore and study the role of horizontal plains and barriers crossing the mussels escape route. On the basis of the results, recommendations for reservoir bowl construction and water release were prepared.

Material and methods

The Czorsztyn Reservoir was constructed on the Dunajec river from 1975–1997. The reservoir catchment includes the Orawsko-Nowotarska valley and areas adjacent to the Tatra, the Gorce and the Pieniny Mts. The reservoir's water surface area is 12.5 km^2, its capacity is 0.2 km^3, and the maximum depth – 50 m. This mountain reservoir bowl is characterized by many bays and tributaries and steep shore slopes, usually with terracing. There are many stump and bush remains that were left on the shores and on the bottom of the Dunajec river valley before the reservoir was filled up.

Water release in the dam reservoir started in September 2007 due to maintenance work on the dam. The initial water level was 527 m a.s.l. and in December 2007, when the work was completed, it dropped to 514 m a.s.l. Average water level decline in the Czorsztyn Reservoir, from September–December 2007, was 1 cm per hour (assessed from the data of the Board of The Czorsztyn-Niedzica-Sromowce Wyżne Water Reservoir Complex).

The research was carried out in December 2007 on the southern shores of the Branicka and Kosarzyska bays. Kosarzyska bay shore slopes are steeper and have distinct terraced areas, and their maximum depth is 25 m (Fig. 1-a). Branicka bay's shores are low sloping (maximum depth 10 m). There were alluvial sediments (mostly sands) on the stream banks, with the deposit thickness of a few centimeters in the Kosarzyska bay (Fig. 1-b). The stream width was 1 to 1.5 m and the depth ranged from 0.5 to 0.7 m.

In order to determine the maximum range of mussel occurrence, line transects parallel to water's edge were established at shores of both bays. Then, every 3 meters, four 40 m long and 2 m width transects were established perpendicularly to the water's edge, at both sites (Fig. 1). Mussels were counted along each transect and their age

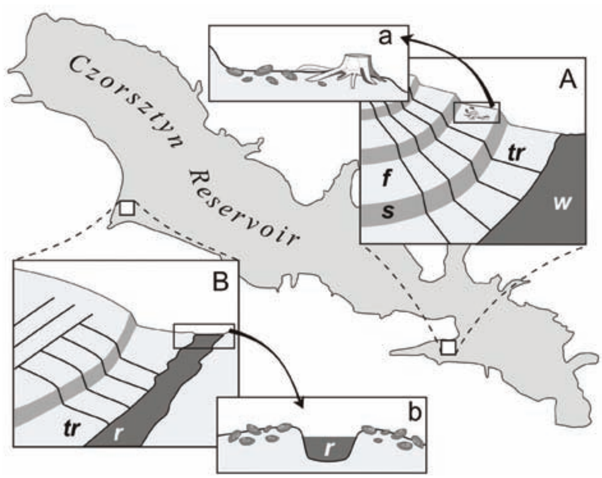

Fig. 1. Sampling scheme in the Czorsztyn reservoir in (A) Kosarzyska bay and (B) Branicka bay. The role of barriers on mussel escape routes: a) trees and bushes, b) alluvial sediments (f – flat slope; s – steep slope; tr – transects; w – water; r – stream).

and position (on the ground or buried in sediments) were noted. To define the possibility of mussel escape from shores of different slopes (slope terracing), the slopes were divided into steep and plane (Strzemski, 1973).

Relationships between factors were studied by applying general linear models (GLM) using Statistica (ver. 8.0 PL). Models were constructed for both bays to evaluate the effects of regressors: transect, place of mussel location (plane slope, steep slope) and the distance from the water's edge (continuous predictor) on response: dead mussel numbers. The model took into consideration interactions of qualitative predicators.

Results

The only freshwater mussel species found in the Czorsztyn reservoir after ten years of operation was duck mussel (*Anodonta anatina*). There were many tracks left by moving mussels on the exposed shores. Circular shaped tracks were characteristic of the plain parts of the terrain surface and ground depressions. On steeper slopes the tracks were fairly straight lines directed alongside the slope. In the side streams entering the reservoir, a few live duck mussels were found. Close to a stream shore line in Branicka bay there were numerous small holes in the ground, where live mussels were also found. They were buried there in damp sand (the upper siphon was at a level of a few centimeters under the ground).

A total of 1,518 dead mussels were found on the transects and the average density of dead individuals on a transect was 2.0 individuals/m^2 (1.0 to 4.0, SD = 1.02, n = 8). On 26 flat slopes of Kosarzyska bay the average density of dead mussels was 3.3 individuals/m^2 (0–14.7, SD = 3.59). On the steep slopes the density was 1.4 indiviuduals/m^2 (0–5.5, SD = 1.65, n slopes = 21). On the 9 flat slopes of Branicka bay the average duck mussel density was 2.9 individuals/m^2 (0.8–12.0, SD = 3.70). On the 8 steep slopes there were 0.5 individuals/m^2 on the average (0–1.9, SD = 0.73). The maximum age of the investigated mussels for both bays was 7 years (2 specimens), with the mean 2.3 years (SD = 0.83, n = 1518).

Statistical analyzes for Branicka bay showed a negative relationship between the dead mussel numbers and the distance from the water's edge (β = -0.44, F = 0.03, $p < 0.001$). The presence of plain slopes, in turn, positively influenced the mussel numbers (β = 0.32, F = 1.86, p = 0.008) (Fig. 2). There was no influence of the transects on mussel numbers and

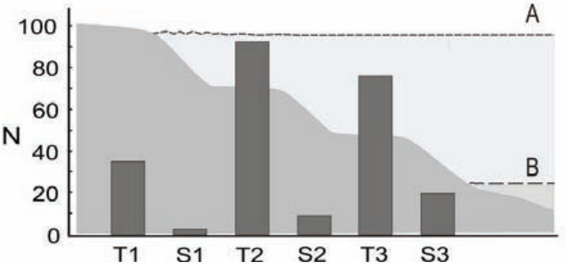

Fig. 2. Mussel distribution in transect 1 in Kosarzyska bay in relation to shore shape, shown in the background (N – mussels number; T1, T2, T3 – flat slopes; S1, S2, S3 – steep slopes; A – the highest water level in the reservoir; B – water level in December 2007).

distribution alongside the slope ($p = 0.421$). Considerable numbers of dead duck mussels were observed also among the stump and bush remains (Fig. 1a). Similarly, at Kosarzyska bay there was a significant influence of: 1) the distance from the water's edge ($\beta = -0.18$, $F = 4.02$, $p = 0.047$) and 2) the place of mussel location ($\beta = 0.19$, $F = 4.73$, $p = 0.031$) on the number of dead mussels. Similarly there were no differences between transects in the mussel number ($p = 0.548$).

Discussion and conclusion

It is unlikely that the observed dead mussel distribution on the Czorsztyn reservoir shores precisely illustrated the localization of live duck mussels inhabiting the lake before releasing the water. Most of the mussels were probably found in places that they had reached during their escape. Abundant tracks left by the mussels on the sand confirm this conclusion. Tracks similar to straight lines suggest that the mussels followed the water's edge decrease, especially on the steep slopes.

The main conclusion is that the higher density of duck mussels on plain slopes and ground depressions show that they were trapped and could not escape. Circle-like tracks on the ground confirm that they were trying to find a slope gradient but did not succeed. High densities of dead mussels were also recorded on plain slopes in the Goczałkowicki reservoir during maintenance work on the dam in 1965 (by Krzyżanek, 1966).

Widuto's (1968) observations of unionids indicate that mussels are able to cover a distance of about 1 m per hour. This author suggests that a fast decrease of water level in a reservoir

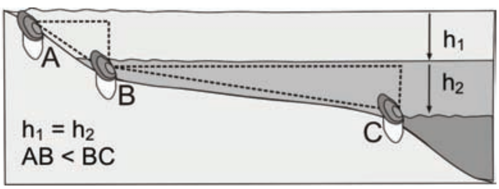

Fig. 3. Dependence between the slope of a reservoir bowl and the distance of mussels' escape to the water while the water level subsides (h_1, h_2 – water level changes; AB, BC – distances of mussel escape routes).

makes it impossible for mussels to escape from a drained area. Indeed, a decrease of the water level of a few centimeters in a lake with gentle shore slopes may very significantly extend escape routes for mussels (Fig. 3). The water decline rate in the Czorsztyn Reservoir must not exceed 20–30 cm per day to prevent the slope's failure (Board of the Czorsztyn-Niedzica-Sromowce Wyżne Water Reservoir Complex). Therefore, according to Widuto's (1968) assumptions, even with gentle shore slopes in the Czorsztyn reservoir, duck mussels should have managed to reach water. Nevertheless, this presumption would be correct only if there had been no additional factors that could have influenced mussel survival.

Lack of any statistical influence of transects on dead mussel location confirms that the transects were set in homogenous conditions. In both Kosarzyska and Branicka bays, the nearer the distance to the water's edge, the increasing number of mussels found on the ground. This could be explained as a result of mussels moving down the shore to reach water during decreasing water levels. Probably the escape route was too long to allow all mussels to get there. Moreover, plain shores disoriented the mussels, which could not perceive the gradient, and thus extended the escape route. In shallow Branicka Bay, mussels were probably moving more freely until they reached small stream embankments where many of them "decided" to bury themselves in wet sediments in order to survive the period without water (Fig. 1b). According to Widuto (1968), freshwater mussels can survive for 30 days without access to water, burying themselves in wet sediments and entering a state of anabiosis.

Possibly, some additional factors could have contributed to the observed massive death of duck mussels. For instance, water decrease in autumn/winter overlapped with the period when duck mussels could have been exhausted after reproduction (Piechocki, Dyduch-Falniowska, 1993; Beerthelin et al., 2000). Furthermore, cold-blooded animals during the winter time reduce their metabolism rate (Gabbott, 1983). Therefore, the mussels could have had lower locomotive ability, which slowed down their escape from the drained parts of the shores. It is also possible that water release was irregular and/or rains caused small flood-waves and/or mussels did not always immediately migrate in response to water level changes. Confirming the role of these factors requires further study.

One of the most serious consequences of such massive mussel death is the degradation of water quality. This is most dangerous for water supply reservoirs. Mussels are suspension feeders and they remove phytoplankton and other suspended particulate matter from water; such reduction of phytoplankton blooms has great impact on drinking water treatment. A single *Anodonta* sp. individual can filter 1.5 l of water per hour (Piechocki, Dyduch-Falniowska, 1993). For example, the Chinese giant mussel, *Anodonta woodiana* is being used as a tool for the biomanipulation in China (Aldridge, 2007; Barclay, 2007). Therefore, mussel protection should be a key issue in dam reservoir management. In order to decrease the losses of freshwater mussel populations inhabiting reservoirs:

- Some refugia on reservoir shores should be designed below the parts inhabited by mussels (Haukioja, Hakala, 1974; Lewandowski, Stańczykowska, 1975; Zając, 2001). This includes remodeling some parts of the reservoir bowl's shore to form a small reservoir permanently filled with water. In the Czorsztyn reservoir such a *refugium* could be designed in Branicka bay. The bay is supplied with stream water and it is fairly shallow, therefore crossing the bay with a small dam/embankment near a stream would provide fresh water in the *refugium*,
- Terraces (steps across the slope) should not be completely plain, but tilted towards the water, especially at low depths (if slope terracing is necessary); this will enable mussels to perceive the slope and escape in the correct direction,

- Mussels should be collected on the lakes' shores during periods of water level decrease and moved back to the water.

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