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Valve movement of freshwater mussel *Anodonta anatina*: a reciprocal transplant experiment between two lakes

Vili Englund & Mikko Heino

Englund, V., Department of Zoology, Division of Physiology, P.O. Box 17, FIN-00014 University of Helsinki, Finland
Heino, M., Department of Zoology, Division of Ecology, P.O. Box 17, FIN-00014 University of Helsinki, Finland

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The effects of caging and source on the valve movements of freshwater mussel *Anodonta anatina* were studied in two different lakes. Caged mussels were compared with those in their natural environment on the lake bottom. In both lakes, the mussels from the study lake and the mussels from the other lake were monitored. Caging was found to increase the valve openness. The source effect was demonstrated in a few treatments. The overall level of valve openness did not differ very much between the lakes. The water temperature was negatively correlated with valve openness in one of the lakes. The correlations between the rate of valve movements and water temperature were of different signs in the two lakes. The particle concentrations, measured by water transparency, had little effect on valve movement. The daily rhythm of valve movement was different between animals at the bottom of the lake and in cages, while the effects of source or study lake were smaller.

1. Introduction

Freshwater mussels are widely used in the monitoring of water quality (Hemelraad 1988, Green et al. 1989, Kramer et al. 1989, Storey & Edward 1989, Mäkelä & Oikari 1990, Herve 1991, Camusso et al. 1994). The use of the mussels for biomonitoring presumes an understanding of the underlying biological phenomena, which, if not taken into account, may seriously compromise the results. Problems that have been paid attention to include the growth rate (Green et al. 1989), the size of animal, the cage type (Muncaster et al. 1990), the source of animals (Green et al. 1989, Hinch & Green 1989), the mistakes that may be made in the identification

of the species (Mäkelä & Oikari 1991), and the depuration of toxicants (Mäkelä et al. 1991). However, behavioural differences between the bivalves originating from different water bodies are still unknown. If the filtration rates of monitored mussels differ between the lakes, the differences in levels of contaminants in the mussels may not reflect the differences in surrounding waters.

The aim of our study was to determine how the source, the destination and the caging affect the valve movements of freshwater mussels. We assume that the filtration rate is a monotone increasing function of valve gaping, at least asymptotically. Jørgensen (1990) has shown this to be true in *Mytilus edulis*. We chose to study the unionid mussel *Anodonta anatina* (Linné), which is a common and abundant species in both lakes and rivers in Europe. The species is widely used for biomonitoring purposes in Europe.

2. Material and methods

The study was carried out in two lakes in southern Finland. Lake Kirmustenjärvi is shallow and eutrophic. Four unionid species are found in the lake in high densities. *Anodonta anatina* is abundant (up to 60 ind./m^2) in shallow water (0–2.5 m). Lake Pääjärvi is a deep and oligotrophic lake, with two unionid species in low numbers. *A. anatina* occurs in depths of 1–7 m, with density usually not exceeding 1 ind./m^2. The mussels were collected and monitored at the same sites. The shell length of the monitored mussels was 67–97 mm for animals collected from Lake Kirmustenjärvi, and 70–105 mm for those collected from Lake Pääjärvi.

The valve movements were registered using a digital monitoring system described by Englund et al. (1994). With this method, three relative positions of the valves could be measured. They were as follows: closed (siphons not visible), open (siphons fully extended), and a half-open position. The weighted valve openness describes the relative openness of the valves during one hour. The time in half-open position was weighted with one half, relative to the time when the valves were fully open. The weighted valve openness varies between 0 and 100%. The activity score is calculated as the rate of valve movements per hour.

As only one monitoring system was available the temporal separation between the experiments in Lake Kirmustenjärvi and Lake Pääjärvi could not be avoided. Therefore we do not apply statistical tests to compare the lakes. In both lakes, a factorial experimental set-up was used, with two treatments: the source of monitored mussels (levels: native or transplanted, i.e. Lake Kirmustenjärvi or Pääjärvi) and the caging (in cage or on lake bottom). The animals monitored at the bottom of the lake were at a depth of two metres, and the caged animals above them at a depth of one metre. Each group consisted of 12 randomly selected mussels. Multivariate analysis of variance (MANOVA) was applied to the data. The weighted valve openness and the activity score were used as dependent variables. To attain normally distributed residuals, a transformation $x' = \log_e(100\% - x)$ (Lake Kirmustenjärvi) or $x' = \sqrt[3]{(100\% - x)}$ (Lake Pääjärvi) was performed to the weighted valve openness, and $x' = \sqrt[3]{x}$ to the activity score in Lake Kirmustenjärvi. The transformations ensured homoschedasticity, except in the case of valve openness in Lake Kirmustenjärvi (Bartlett's test, $P = 0.006$), thus increasing probability of type I error. The shell length was tried as a covariate, but was omitted as insignificant. Nor did sex, gravidity or parasitism have detectable effects with present sample sizes. In correlation analyses, Kendall's rank correlation coefficients (r_K) were used.

In Lake Kirmustenjärvi, mussels were monitored for a period ranging from June 1st to July 4th, 1993. In Lake Pääjärvi, monitoring was started on the 10th of July and was continued until the 16th of August. The setting up and adjustment of the monitoring system took 3–4 days, during which the mussels were able to acclimate. The lake-bottom mussels were placed at the bottom of the lake, along a two-metre depth contour in a 20-metre sequence, wherein transplanted and native mussels were placed alternately. The caged animals were above the lake-bottom mussels, at a depth of one metre, in small plastic cages hanging from a float. Secchi disc transparency was measured at intervals of 1 to 4 days. Temperatures were automatically recorded every ten minutes at depths of one and two metres.

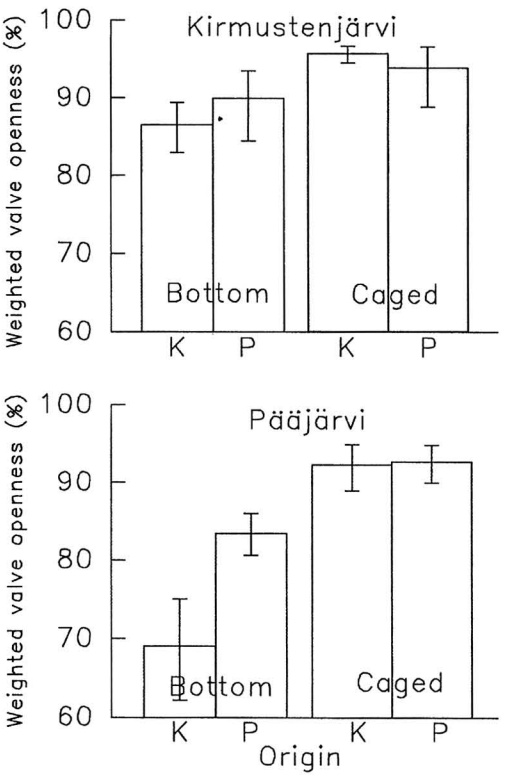

Fig. 1. The weighted valve openness of *Anodonta anatina* when exposed to different treatments: source lake and caging vs. lake bottom. On the horizontal axis, the source lake is indicated with the letters K and P for Lake Kirmustenjärvi and Lake Pääjärvi, respectively. Each bar represents the average of twelve animals. The 95% confidence intervals calculated on transformed scales are indicated with vertical bars.

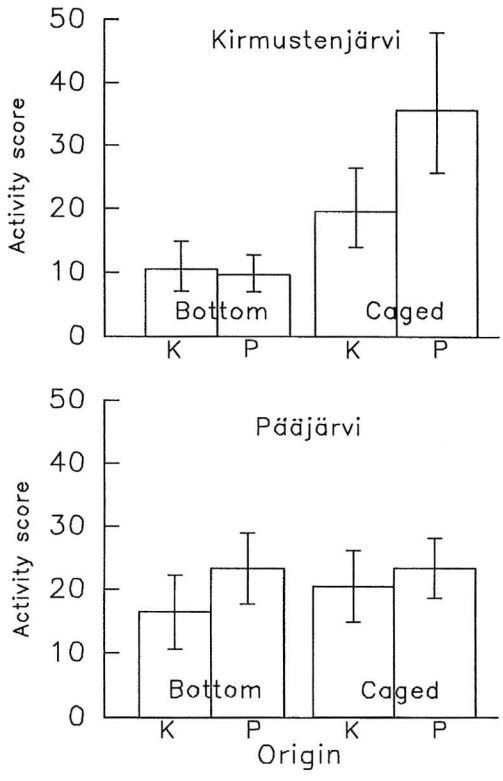

Fig. 2. The activity score of *Anodonta anatina* when exposed to different treatments: source lake and caging vs. lake bottom. See Fig. 1 for the explanation.

3. Results

The valve movement of *Anodonta anatina* differed between the treatments (Table 1). The overall effect of caging is the most important, which is also obvious in Figs. 1 and 2. In Lake Pääjärvi, the source affects valve openness, and the mussels of different origin react to the caging differently. In Lake Kirmustenjärvi the source affects only the activity score via the interaction term. The overall levels of weighted valve openness, 89.3% (*SE* 1.3) in Lake Kirmustenjärvi and 83.5% (*SE* 1.8) in Lake Pääjärvi, do not differ very much between the lakes, in spite of both the seasonal effects and the water quality differences.

The daily rhythm of caged mussels is different from that of the lake-bottom animals (Fig. 3). The valve openness of lake-bottom mussels shows a peak late at night. In the caged mussels, the valve openness remains at a high level for almost the whole day, with a small decrease in the early morning (Fig. 3). The pattern is little affected by the study lake, and the effect of source lake is negligible. Thus, the daily rhythm seems to be governed mainly by prevalent conditions.

The correlation coefficients between secchi depths and daily averages of the weighted valve openness are insignificant, with one exception: the native mussels in Lake Kirmustenjärvi decrease their valve openness when secchi depths are greater (Table 2). There is a significant correlation between the activity score and the secchi depth in the non-native caged mussels in both lakes, but these correlations are of different signs.

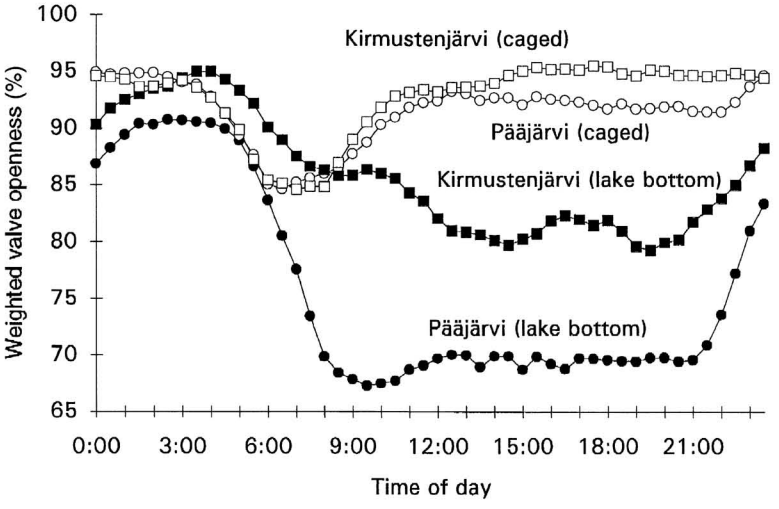

Fig. 3. The daily rhythm in the weighted valve openness of *Anodonta anatina*. The pattern is different between the caged and lake-bottom animals, but the difference between the study lakes is less pronounced. The source lake has little effect so the data is pooled. The 95% confidence intervals calculated on untransformed scales are on average ±1.9 (range: 0.9–2.8).

In Lake Pääjärvi increased activity scores are associated with high water temperatures, while valve openness is not affected (Table 2). In Lake Kirmustenjärvi, activity score of the caged mussels is negatively correlated with water temperature. In the lake-bottom mussels the same pattern is seen between weighted valve openness and temperature (Table 2).

4. Discussion

Caging had, by far, the greatest effect on the valve movement of *Anodonta anatina*. The environmental conditions to which the lake-bottom and caged mussels were exposed differ very much. In cages, the mussels are unable to burrow, and are thus subjected to shaking caused by wave action. Due to the depth difference, the physical, chemical and biological properties of ambient water are dissimilar. A more controlled experiment is needed to reveal the true nature of the 'caging effect'.

In our study, the source effect demonstrates both the stress effect of transplanting procedure, and the effect of acclimation to a different environment. However, only in the case of the lake-bottom animals monitored in Lake Pääjärvi, is

Table 1. Multivariate (Wilks' Λ) and univariate F-statistics of MANOVA for the valve movement of *Anodonta anatina*. In the case of valve openness in Lake Kimustenjärvi, actual probabilities of rejecting a true null hypothesis are somewhat higher than indicated, due to the heteroscedasticity.

Study lake	Wilks' Λ		Weighted valve openness		Activity score	
Effect	*F*	*P*	*F*	*P*	*F*	*P*
Lake Kirmustenjärvi						
Caging	47.5	<0.001	15.6	<0.001	33.6	<0.001
Source	2.08	0.137	0.03	0.868	3.45	0.070
Caging*Source	2.67	0.081	2.46	0.124	5.25	0.027
Lake Pääjärvi						
Caging	24.5	<0.001	47.0	<0.001	0.58	0.451
Source	8.94	0.001	13.1	0.001	3.08	0.086
Caging*Source	6.13	0.005	11.1	0.002	0.52	0.474

there a considerable difference in valve openness between mussels of different origins (Fig. 1). Since the difference was evident for the whole study period, it is probably caused by acclimation to the pre-transplant lake.

Jokela (1993) has emphasized the importance of adaptive plasticity in the life history of *A. anatina*. The plasticity of valve movement behaviour appears to be considerable, too. However, Hinch & Green (1989) have found significant source effect in tissue metal concentrations and growth rates of transplanted freshwater mussels (*Elliptio complanata*). They postulate that this may be due to the genetic differences found between the source populations. In *Lamsilis radiata*, growth rate was affected by the source of the mussels, while the shell shape was not affected (Hinch et al. 1986).

Ingestion rate sets an upper limit to the amount of food that is filtered from the water (Sprung & Rose 1988). As secchi disc transparency can be used as an inverse index of food particle concentration, positive correlation between valve openness and secchi depth can be predicted (Davids 1964, Sprung & Rose 1988). Actually, no significant positive correlations were found (Table 2). However, in eutrophic Lake Kirmustenjärvi, contrary to the expected, when water turbidity increases, animals on the lake bottom increased their valve openness. This pattern was also seen between the lakes: the average valve openness was higher in the eutrophic Lake Kirmustenjärvi than in the oligotrophic Lake Pääjärvi (Fig. 1). However, in *Mytilus edulis*, the filtration rate may be depressed at extremely dilute suspensions, at least in the short run (Davenport & Woolmington 1982).

Salánki et al. (1974) found that increasing water temperature was associated with increased activity and decreased valve openness. The same pattern was also found in this study. However, the activity of the transplanted animals in cages decreased in Lake Kirmustenjärvi, when the temperature was higher. The temperature differences between the study lakes were small (mean temperature at a depth of one metre 16.0°C in Lake Kirmustenjärvi, 16.8°C in Lake Pääjärvi).

Interannual differences in the valve movements of mussels are considerable. The data from mussels monitored and collected in Lake Kirmustenjärvi, on the lake bottom, is comparable to the data in Englund & Heino (1994): the average weighted valve openness (±*SD*) was 56.7±24.7% in 1992, and 85.4±6.5% in this study. This discrepancy may be caused by a much higher water temperature during the former study (19.8

Table 2. Correlation coefficients between daily temperatures, secchi depths and daily averages of the weighted valve openness and activity score in *Anodonta anatina*. Secchi depth measurements exist from 29 days in Lake Kirmustenjärvi and from 19 days in Lake Pääjärvi. Temperatures were recorded at depths of one (caged animals) and two (lake-bottom animals) metres. Sample size is 32 in Lake Kirmustenjärvi and 37 in Lake Pääjärvi. Statistically significant ($P \leq 0.05$) values are emphasized. In correlation analyses, Kendall's rank correlation coefficients (r_K) were used.

Study lake / Source		Temperature: Weighted valve openness	Temperature: Activity score	Secchi depth: Weighted valve openness	Secchi depth: Activity score
Lake Kirmustenjärvi					
Kirmustenjärvi	Bottom	–0.365	–0.052	–0.264	–0.036
	Cage	–0.123	–0.049	–0.093	–0.341
Pääjärvi	Bottom	–0.273	0.230	–0.422	–0.059
	Cage	–0.198	–0.293	–0.160	–0.570
Lake Pääjärvi					
Pääjärvi	Bottom	0.226	–0.144	0.132	0.232
	Cage	0.103	0.185	–0.081	0.337
Kirmustenjärvi	Bottom	0.322	0.240	0.018	0.259
	Cage	–0.185	0.405	–0.086	0.227

vs. 15.5°C at a depth of two metres). At any rate, this casts some doubt to the predictive value of our experiments.

The daily rhythm of the lake-bottom animals in this study is remarkably similar to that found earlier (Englund & Heino 1994). A similar rhythm was found by McCorkle et al. (1979) in the unionid *Ligumia subrostrata* in the laboratory. They state that the activity rhythm was determined by light rhythm. This may explain why valve openness decreases earlier in the morning in the caged animals as compared with the lake-bottom animals. However, unionids possess also endogenous rhythms (Morton 1970, McCorkle et al. 1979).

Factors affecting the valve movements are diverse, and include the effects of toxicants (Davids 1964, Salánki et al. 1974, Sprung & Rose 1988, Kramer et al. 1989, Salánki & V.-Balogh 1989, Mäkelä & Oikari 1990, Mersch et al. 1993). More studies are needed for the full understanding of the valve movements of freshwater mussels in nature, and before this knowledge can effectively be used in biomonitoring. Thus, it is not totally surprising that predictions made from one variable alone (e.g. particle concentration) may fail in the nature. Still, some interesting results concerning biomonitoring emerge from this study. Firstly, caging is a good practice, since it increases valve openness. Secondly, the common practice of transplanting mussels from a source lake to various test lakes does not seem to have any tremendous consequences. Thirdly, although valve openness did not vary very much between the two lakes under study, interannual variation seems to be considerable. Thus, if valve openness is correlated with filtration activity, and this in turn with accumulated toxicants, different environmental conditions in study sites may produce artefacts into results. Quantitative conclusions made from varying tissue concentrations of toxicants should only be made with uttermost care.

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