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Valve movement of *Anodonta anatina* and *Unio tumidus* (Bivalvia, Unionidae) in a eutrophic lake

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The valve movement of two unionid mussel species, *Anodonta anatina* and *Unio tumidus*, was recorded with the aid of a digital monitoring system in a eutrophic lake in southern Finland. The animals were in their natural environment at the bottom of the lake, where they moved freely. The mussels were monitored for 22 days. Both species displayed a diurnal rhythm of valve gaping, although the rhythm was much more pronounced in *Anodonta anatina*. The state of openness of the shell was highest at night and lowest in the morning. The valve openness of *Unio tumidus* was greater than that of *A. anatina*, which was mainly due to the fact that the former species seldom has its valves fully closed. The rate of valve movement was significantly greater in *A. anatina* than in *U. tumidus*. There were significant long term fluctuations in valve openness for both species.

1. Introduction

Biological sensors are becoming more important in monitoring the quality of the aquatic environment. As bivalves can circulate several tens of litres of water daily and thus enrich pollutants to tissue concentrations ranging from 1000 to 10000 times of that in the surrounding water (Pynnönen 1991), they have been used as indicators of both water quality and pollutant levels (Green et al. 1989, Kramer et al. 1989, Muncaster et al. 1990, Mäkelä & Oikari 1990, Herve 1991, Mäkelä et al. 1991). The efficiency of water filtration, and the degree of gaping of the valves may greatly affect the enrichment rate of pollutants and the sensitivity of bivalves as environmental monitoring organisms. High density populations of suspension-feeding bivalves may have a significant effect on phytoplankton densities and water purification (Jørgensen 1990).

Rhythmical valve movement in bivalves has been described by many workers (Barnes 1955, 1962, Salánki & Balla 1964, Salánki & Veró 1969, Morton 1970, Kramer et al. 1989, Pynnönen 1991). Unfortunately, most of the experiments on the behaviour of the mussels have been carried

out under laboratory conditions. Using mussels for biomonitoring presumes an understanding of their filtering activity under natural conditions. In this paper we describe the valve movements of two unionid species in their natural environment.

2. Material and methods

Lake Kirmustenjärvi is a eutrophic lake situated in southern Finland (Järnefelt 1925, Table 1). Four freshwater mussel species, *Anodonta anatina* (Linné), *Pseudanodonta complanata* (Rossmaesler), *Unio pictorum* (Linné) and *U. tumidus* Philipsson (Bivalvia, Unionidae) inhabit the lake. The mussel densities may be very high (up to 200 ind./m^2). The two commonest species, *A. anatina* and *U. tumidus*, were chosen for this study. *A. anatina* is also used for biomonitoring in Finland.

The wave action in the study area was low and there were no strong water currents. The mussels were collected from a depth of two metres, and monitored on site, in the sublittoral zone of the lake. At the study site the density of *Anodonta anatina* was about 40 ind./m^2, and the density of *Unio tumidus* about 80 ind./m^2. The bottom of the lake was a mixture of sand, silt and the shells of dead mussels.

Valve movements were recorded continuously using a digital monitoring system described by Englund et al. (1994). The method allows the mussels to move freely. Two mechanical switches were attached to the mussels, representing the valve status between the open and the closed state. The states were as follows: closed (siphons are not visible), open (siphons are fully extended), and medium half-opened position. The shells of the mussels were cleaned and the switches were fastened to the surface. As no mussel was above the surface of the water for more than 15 minutes any disturbing effect would have been negligible. The mussels were placed at the bottom of the lake on a 20 metre sequence along the two metre depth contour, the species being spatially separated. After four days, the study period began and lasted for three weeks (May 30th to June 21st 1992). Twelve mussels of both species were monitored simultaneously. The median length of the mussels was 79 mm (range: 74–87 mm) for *Unio tumidus* and 84 mm (76–96 mm) for *Anodonta anatina*. The water temperature was measured automatically every ten minutes at two levels. Level one was at 10 cm above the bottom of the lake, level two at 5 cm inside the bed of the lake.

The mussel activity is scored as the number of valve movements per hour. The weighted valve opening describes the relative openness of the valves during one hour. The time in medium

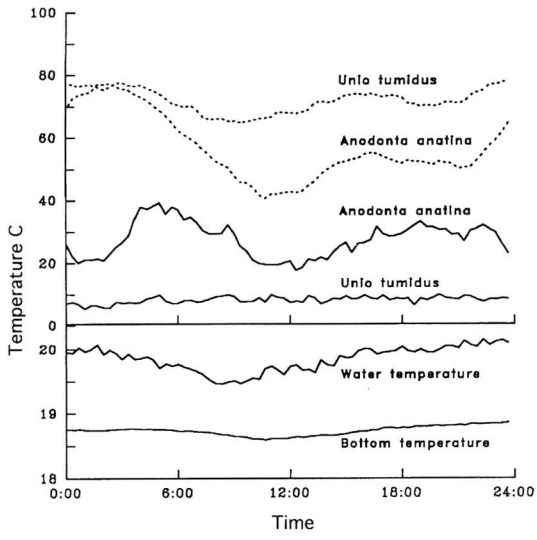

Fig. 1. "An average day", i.e. the average values of the given time of day from the 22 day study period. In the upper panel activity scores are drawn with a solid line, weighted valve openness values with a dotted line. Values are averages of twelve animals. Temperatures were measured inside the lake bed and from water just above the bottom.

Table 1. Hydrology and water chemistry of Lake Kirmustenjärvi. Values are summer averages. Chlorophyll-a and calcium values are based on only one measurement.

Surface area km^2	4.1
Mean depth m	2
Maximum depth m	6.5
Secchi depth m	1.3–1.5
Total phosphorous µg/l	60
Chlorophyll-a µg/l	9.5
pH	7–8
Calcium mg/l	7.3
Alkalinity mmol/l	0.32

position is weighted with one half. Thus, we have the weighted valve openness as: $100(t_m/2 + t_o)/t_{tot}$ (where t_m is time with valves in medium position during a time interval, t_o is time with valves open and t_{tot} is total time).

Variability between individual mussels is very high, and the method used to record the valve movements is approximate. We chose, therefore, to use only group averages to indicate that the results are valid only as population parameters. More accuracy could be gained by taking the physiotype of the study animals into account, but this is not possible with the present sample size, limited by the capacity of the monitoring system.

3. Results

Both species displayed rhythmical behaviour of the valve movements and openness (Fig. 1). In *Anodonta anatina* a diurnal rhythm is seen; the mussels were mostly open during the night. The valve openness had its lowest value before noon (Fig. 1). The activity score displayed a 12 hour rhythm: one peak in the early morning, the other in the evening. *Unio tumidus* also exhibited diurnal rhythm in valve openness, although the amplitude of the openness curve was much lower than in *A. anatina* (Fig. 1). However, in both species the shapes of the daily openness curves were remarkably similar. The lowest values of valve openness occurred before noon, the highest in the late evening before midnight. The activity of *U. tumidus* did not display any diurnal pattern (Fig. 1). The daily rhythm of mussels was correlated with temperature variations (Table 2). Weighted valve openness for both species was significantly correlated with water and bottom temperatures (Fig. 1). The activity score of *A. anatina* was significantly correlated with bottom temperature.

Interspecific differences can be seen in valve gaping between the two species (Fig. 2). *U. tumidus* seldom had its valves closed, as compared to *A. anatina*, which spent one third of the time with its valves closed (Table 3). In medium position the opposite is true, although the difference is not statistically significant, due to great intraspecific variation. Both species had their valves fully open roughly the same amount of time (Table 3). The weighted valve openness of *U. tumidus* was greater than that of *A. anatina*,

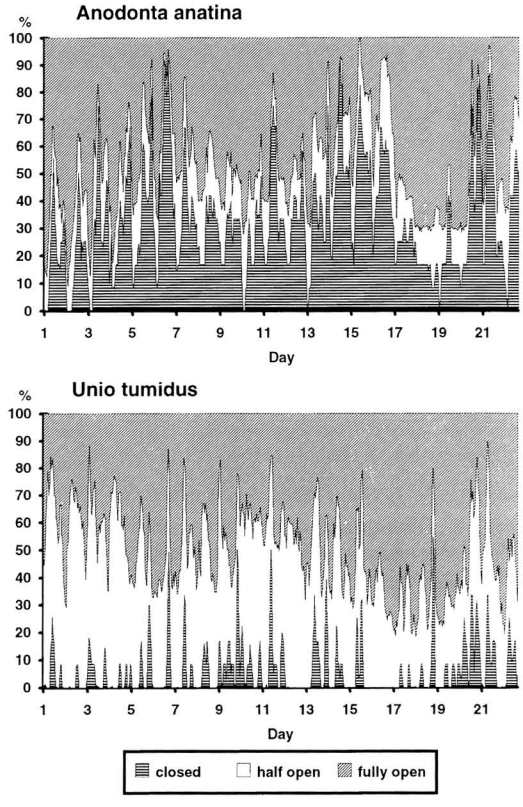

Fig. 2. The percentages of time spent in three relative positions of valves in *Anodonta anatina* and *Unio tumidus*, based on averages of twelve animals.

Table 2. Correlation coefficients between temperature and weighted valve openness and activity score based on the data in Fig. 1. Time interval is 20 minutes, giving $n = 72$. Coefficients statistically significantly differing from zero are marked with an asterisk.

	Temperature	
	Water	Bottom
A. anatina		
Valve openness	0.377*	0.471*
Activity score	0.100	0.519*
U. tumidus		
Valve openness	0.779*	0.668*
Activity score	–0.127	–0.019

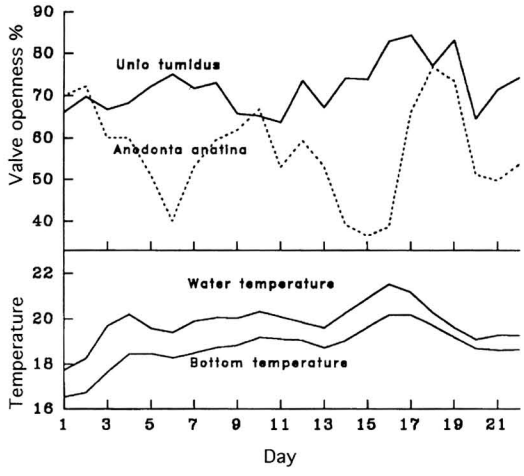

Fig. 3. Changes in weighted valve openness of *Anodonta anatina* and *Unio tumidus*, and in water and bottom temperatures during the study period.

which is mainly due to the difference in time spent with closed valves (Table 3). The reverse is true for the activity score. *A. anatina* exhibited about three times more valve movements per hour than *U. tumidus*. There were substantial long term fluctuations in the openness indices for both species (Fig. 3). The study period was not long enough to determine whether these fluctuations were rhythms with a longer period. Temperature did not explain long term trends in the weighted valve openness (correlation coefficients between –0.14 and 0.30).

4. Discussion

Our results on the rhythmical valve movement of mussels are different from those presented in most previous studies (Barnes 1955, 1962, Morton 1970, Pynnönen 1991). It appears that under laboratory conditions the rhythms are very regular, and the animals have their valves closed for most of the time. We believe that the deviations are due to sterile conditions associated with laboratory environments, or by the stress caused by the recording method. Our results resemble those of Salánki & Véró (1969), the only field study published. Unfortunately, their data was based on very few animals, and intraspecific variation was very high.

The majority of relevant physico-chemical and biological variables display diurnal variations, which are strongly intercorrelated. Of these, only the temperature was measured in our study. Therefore, the correlation between temperature and the daily rhythm of mussels cannot be considered indicative of any causal relationship. Salánki et al. (1974) found that fast and/or large changes in water temperature have an impact on the valve movements. However, in our study the rate of water temperature change at both levels was both small and slow.

The light-dark rhythm is an important activity regulator for many animals. Salánki (1966) found that diurnal rhythm in *Pecten jacobaeus* Linné and *Lithophaga lithophaga* (Linné) depends on the illumination changes. He also noticed that the daily rhythm of these two marine bivalves can be shifted by lengthening the light or the dark periods. Braun & Job (1965) showed that *Unio pictorum* reacts to changes in light intensity. Photosensitive cells have not been reported in unionid mussels, but they are consid-

Table 3. The percentage of time in different valve positions, weighted valve openness and activity score. The differences in values are tested with Student's t-test. Variances are unequal except in the first and fourth cases. $n_1 = n_2 = 12$.

	A. anatina	*U. tumidu*	sp
Fully open			
mean	46.2	53.2	0.603
SD	29.3	35.1	
Medium position			
mean	19.1	39.6	0.095
SD	19.3	35.2	
Closed			
mean	34.7	7.2	0.001
SD	24.5	2.0	
Weighted valve openness			
mean	56.7	72.0	0.094
SD	24.7	17.7	
Activity score			
mean	27.0	8.3	0.001
SD	19.3	4.0	

ered to be widely distributed among the class Bivalvia (Charles 1966).

Salánki & Véró (1969) proposed that the increased openness at night is caused by the decreasing oxygen level. However, it is improbable that the respiratory needs govern the daily rhythm, because in the laboratory the mussels often have their valves closed for almost the whole day (Barnes 1955, 1962, Morton 1970, Pynnönen 1991). Thus, it is likely that valve openness is mainly determined by the filtering activity. According to Morton (1970), the rhythm is endogenous and related to feeding and digestion. However, under natural conditions it is very probable that feeding is also controlled by external factors. It is likely that there are daily differences in the availability of food organisms, but little is known about the migrations of plankton in the sublittoral zone.

The similarity of the pattern in daily variations of valve openness of *Anodonta anatina* and *Unio tumidus* may well reflect a common explanation. Both curves exhibit one peak in the early morning and another in the evening, seen in weighted valve openness in Fig. 1. Curves of this type may well be produced by the interaction of two simple cyclical phenomena, which may be involved in feeding and digestion (Morton 1970). The activity period of *A. anatina* in the early morning coincides with the time valve openness declines to its lowest values. It is possible that this is caused by the animals gradually closing their shells after feeding during the night. The activity period in the evening is not so clearly involved in changes of valve openness; it may be caused, however, by the expulsion of faeces.

If valve movements are to be used in the assessment of pumping rate, it should be confirmed that these are in relation to each other. According to Jørgensen et al. (1988), there is a linear relationship between valve gaping and the pumping rate in *Mytilus edulis*. Particle concentrations are known to influence the pumping rates of mussels (Sprung & Rose 1988). This may well explain the marked variability in valve movements between different days. We measured secchi depths, but unfortunately the measurements were too scattered to yield any defined pattern.

Ingestion rate sets an upper limit to the amount of food which is filtered from the water (Sprung & Rose 1988). Judging from weighted valve openness, there are more food particles in the water than can be ingested by the mussel population during the early summer in Lake Kirmustenjärvi. Moreover, this food excess seems to be greater for *Anodonta anatina* than for *Unio tumidus*. This is consistent with the occurrence of these two species in the Finnish lakes: *A. anatina* occurs in both oligotrophic and eutrophic lakes, while *U. tumidus* is restricted mainly to eutrophic lakes (unpublished data).

Fluctuations in valve openness may be reflected in the enrichment of pollutants in the mussels. A mussel filtering for most of the time would be ideal for biomonitoring. In this respect *Unio tumidus* is more suitable for biomonitoring than *A. anatina*.

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References

Barnes, G. E. 1955: The behaviour of Anodonta cygnea L., and its neurophysiological basis. — J. Exp. Biol. 32:158–174.

— 1962: The behaviour of unrestrained Anodonta. — Anim. Behav. 10:174–176.

Braun, R. & Job, W. 1965: Neues zum Lichtsinn augenloser Muscheln. — Naturwissenschaften 52:482.

Charles, G. H. 1966: Sense organs (less cephalopods) — In: Wilbur, K. M. & Yonge, C. M. (eds.), Physiology of Mollusca. Volume II: 455–521.

Englund, V., Heino, M. & Melas, G. 1994: Field method for monitoring valve movements of mussels. — Water Research, in press.

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

Herve, S. 1991: Mussel incubation method for monitoring organochlorine compounds in freshwater recipients of pulp and paper industry. — PhD dissert., Faculty of Science, University of Jyväskylä, Research report No. 36. 95 pp. + 11 App.

Järnefelt, H. 1925: Zur Limnologie einiger Gewässer Finnlands. — Ann. Soc. Zool.-Bot. Fenn. Vanamo 2:185–352.

Jørgensen, C. B., Larsen, P. S., Möhlenberg, F. & Riisgård, H. U. 1988: The mussel pump: properties and modelling. — Mar. Ecol. Prog. Ser. 45:205–216.

Jørgensen, C. B. 1990: Bivalve filter feeding: hydrodynamics, bioenergetics, physiology and ecology. — Olsen & Olsen, Fredensborg. 140 pp.

Kramer, K. J. M., Jenner, H. A. & de Zwart, D. 1989: The valve movement response of mussels: a tool in biological monitoring. — Hydrobiologia 188/189:433–443.

Morton, B. 1970: The rhythmical behaviour of Anodonta cygnea L. and Unio pictorum L. and its biological significance. — Forma Functio 2:110–120.

Muncaster, B.W., Hebert, P. D. N. & Lazar, R. 1990: Biological and physical factors affecting the body burden of organic contaminants in freshwater mussels. — Arch. Environ. Contam. Toxicol. 19:25–34.

Mäkelä, T. P. & Oikari, A. O. J. 1990: Uptake and body distribution of chlorinated phenolics in the freshwater mussel, (Anodonta anatina L.). — Ecotoxicol. Environ. Saf. 20:354–362.

Mäkelä, T. P., Petäinen, T., Kukkonen, J. & Oikari,A. O.J. 1991: Accumulation and depuration of chlorinated phenols in the freshwater mussel (Anodonta anatina L.). — Ecotoxicol. Environ. Saf. 22:153–163.

Pynnönen, K. 1991: Effect of acidification in freshwater clams (Unionidae). — PhD dissert., Faculty of Science, University of Helsinki. Yliopistopaino, Helsinki. 40 pp. + 8 App.

Salánki, J. 1966: Daily activity rhythm of two Mediterranean lamellibranchia (Pecten jacobaeus and Lithophaga lithophaga) regulated by light-dark period. — Annal. Biol. Tihany 33:135–142.

Salánki, J. & Balla, L. 1964: Ink-lever equipment for continuous recording of activity in mussels. — Ann. Biol. Tihany 31:117–121.

Salánki, J., Lukacsovics, F. & Hiripi, L. 1974: The effect of temperature variations on the rhythmic and periodic activity of the fresh water mussel (Anodonta cygnea L.). — Ann. Biol. Tihany 41:69–79.

Salánki, J. & Véró M. 1969: Diurnal rhythm of activity in freshwater mussel (Anodonta cygnea L.) under natural conditions. — Ann. Biol. Tihany 36:95–107.

Sprung, M. & Rose, M 1988: Influence of food size and food quantity on the feeding of the mussel Dreissena polymorpha. — Oecologia 77:526–532.