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THE CULTURE OF JUVENILE FRESHWATER PEARL MUSSELS *Margaritifera margaritifera* L. IN CAGES: A CONTRIBUTION TO CONSERVATION PROGRAMMES AND THE KNOWLEDGE OF HABITAT REQUIREMENTS*

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Abstract

The culture of juvenile Margaritifera margaritifera *in cages is shown to be a useful method of raising the early post-parasitic stages in suitable rivers for scientific or conservation purposes. Survival rates of caged specimens are equal to those of free-living juveniles, and growth is equal or slower than under natural conditions. Factors affecting the viability of caged juveniles are: length of the shell, colonisation of cages by aquatic insects and amount of fine sediments accumulating in the cages.*

The influence of 12 water chemistry variables on the juveniles is analysed: growth and mortality largely depend upon water temperature; there is a negative relationship between growth and eutrophication.

Keywords: Margaritifera, culture, conservation, temperature, eutrophication.

INTRODUCTION

During this century the freshwater pearl mussel *Margaritifera margaritifera* L. has become extinct in wide parts of Central Europe. Where populations survive, losses range up to 90% and more (Bauer *et al.*, 1980; Baer & Steffens, 1987; Wächtler *et al.*, 1987). The reasons for these losses are still debated. Pearl fishing has certainly contributed and consequently is now prohibited or regulated in the EC countries. However, it is not sufficient as an explanation for this decline, for professional pearl fishermen take adult mussels only (Young & Williams, 1983) and leave the young untouched. Therefore populations that are unaffected in other respects may have a chance to recover, even after severe pearl fishing.

During their life cycles, unionoid mussels have to pass two critical phases, which make the species vulnerable to changes in their habitats (Coker *et al.*, 1919–20):

(1) Glochidia must reach the gill tissue of a host fish soon after their release into the current. Bauer (1989) and Young and Williams (1984) estimate that out of every 1 million glochidia produced by *M. margaritifera*, less than 10 succeed in infecting a suitable host and developing into a young mussel. Furthermore these enormous losses seem to be the rule even in undisturbed habitats. They are counterbalanced by a high life expectancy and the vast numbers of glochidia released by the females: according to Bauer (1989) a female *M. margaritifera* produces up to 200 million glochidia during its life span.

(2) The second critical phase is the early post-parasitic stage (Bauer, 1988). For several years the juvenile mussels inhabit the interstitial zone of the river bed. There they are restricted to microhabitats that show high rates of exchange between the free water body and interstitial water (Buddensiek *et al.*, 1993*a*). During this phase the juvenile mussels are threatened by even slight eutrophication (Bauer *et al.*, 1980; Buddensiek, in press) and in some cases also by the intrusion of fine sand, which prevents exchange between the interstitial zone and flowing water (Buddensiek *et al.*, 1993*b*).

As adults remain fertile even in organically polluted habitats, and the main host of *M. margaritifera*, the brown trout *Salmo trutta*, is still abundant in rivers where the species has disappeared, the decline of the freshwater pearl mussel is evidently caused by death at the early post-parasitic stage. Hence it is the presence or absence of juvenile *M. margaritifera* that gives the best information on the status and long-term survival of a population.

A strategy for conserving small populations, or those existing in more or less polluted rivers, is to infect high numbers of host fish artificially with glochidia. By this means, the number of juvenile mussels that enter the interstitial zone can easily be multiplied. If mortality of the juveniles is not absolutely 100% in such water systems, then some of these young mussels have a chance to grow up and contribute to a new stock of adults. Nevertheless losses are high, as many juveniles that eventually leave from the host fish will drop onto parts of the sediment that are unsuitable for mussels. The culture system described in this paper allows the newly released mussels to be kept until they have passed the first critical phase and then released directly into areas of high quality sediment.

*Dedicated to Wolf-Dietrich Bischoff.

The transfer of adult *M. margaritifera* from one river to another, where it had previously disappeared or never existed, has been tried several times, mainly for purposes other than species conservation. Early reports on such attempts date back to the last century (von Hessling, 1859); Jungbluth (1970) lists several ineffective transfers and states that only one is known to have been successful, while in all other cases the animals died or disappeared within a very short time. Even when adult freshwater pearl mussels of one population were transferred to a river holding another population of the species, animals disappeared within a short time (Baer & Steffens, 1987).

This paper describes a method of rearing juvenile *M. margaritifera* and gives first results of their culture in northern German rivers, as well as results on the success of transfer of juvenile freshwater pearl mussels from one water system to another.

METHODS

The culture system

To provide high numbers of early post-parasitic stages of the freshwater pearl mussel, artificially infected host fish (brown trout) were kept in aquaria during the time of release of the young mussels. These were then collected daily by carefully exhausting water from the bottom of the aquaria via a tube through a 200 μm plastic gauze, from which the mussels were transferred into a multiple cage (Fig. 1).

This cage system consists of three plates of plastic (polyacryl, 125 × 85 mm) into which 96 holes are drilled (6·0 mm diameter). The early post-parasitic stages were enclosed within 92 holes of the 9-mm thick central plate by two sheets of plastic gauze (200 μm mesh) held in place by 2-mm thick outer plates using four stainless steel screws. Five young mussels were placed in each cell, giving a total of 460 for each plate. Plates were transferred to four rivers in the Luneburg Heathlands (northern Germany), where they were fastened above the bottom, facing the current.

The water systems

River A1 is inhabited by the last remaining population of *M. margaritifera* in northern Germany. Its water quality is higher (e.g. oxygen, temperature, electrical conductivity, inorganic nitrogen, phosphate) than that of river A2, into which it discharges, and which held a stock of freshwater pearl mussels until the early 1980s. River A2 is the most polluted of the rivers studied.

Rivers B and C belong to other catchments of the Luneburg Heathlands and their water quality is higher than that of the rivers of system A. However, only dead shells are known from river B; there are no records on the time of the species' disappearance from that river and the cause of the extinction is not known. River C has probably never been a pearl mussel river; it was included in this study because of its very high water quality. For comparison the annual means of 12 water chemistry variables are presented in Table 1.

Factors influencing juvenile mussels

Survival and growth rates were determined at intervals in the laboratory by counting the surviving juveniles and measuring a randomly chosen sample of at least 30 specimens. Juveniles were transported and kept in the laboratory in aerated water from the rivers; the water

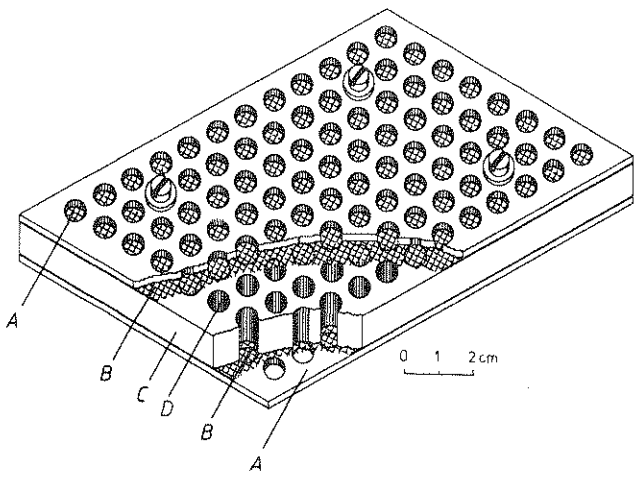

Fig. 1. Culture system: A, covering plate; B, plastic gauze; C, central plate; D, single cage.

Table 1. Environmental data from four rivers; annual means (standard deviation) of 12 variables measured in the free waterbody

	A1		A2		B		C	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Temperature (°C)	9·50	4·91	10·39	5·50	9·78	4·07	9·41	2·71
O_2 (mg/l)	9·76	0·99	9·41	1·73	10·55	1·51	11·01	0·94
Conductivity (μS)	208·20	32·06	283·00	49·07	174·50	38·97	116·31	24·47
pH	7·05	0·27	6·96	0·34	7·11	0·32	6·72	0·53
NH_4 (mg N/l)	0·22	0·07	0·34	0·13	0·17	0·07	0·16	0·07
NO_2 (mg N/l)	0·01	0·01	0·02	0·01	0·01	0·01	0·01	0·00
NO_3 (mg N/l)	3·17	1·01	4·19	1·55	1·27	0·61	2·22	0·52
PO_4 (mg/l)	0·11	0·03	0·16	0·05	0·20	0·14	0·11	0·07
Na (mg/l)	15·64	1·55	19·06	2·23	15·89	1·09	14·36	1·72
K (mg/l)	4·25	0·76	6·09	1·26	1·99	0·33	2·38	0·51
Ca (mg/l)	11·30	2·71	14·29	3·18	10·00	1·24	5·48	0·90
Mg (mg/l)	3·98	0·33	4·84	0·42	2·70	0·24	2·18	0·19

temperature in the laboratory was adjusted to the temperature in river A1.

To study the potential influence of mussel size on their survival during their first winter, 241 juveniles were measured individually in the laboratory in autumn at the age of 3 months and were then separated into six size classes (< 500, < 600, < 700, < 800, < 900, > 900 μm). After 7 months' exposure in river A1, survival rates were determined for each size class. The number of animals included in each class at the start was equivalent to its percentage within the population of juveniles at that time.

Preliminary results indicated that the viability of juvenile mussels was affected by other animals which colonised the plates and the quantity of fine particulate matter carried into the cells. To study these potential influences, each cell of 15 plates studied was checked for surviving mussels, the presence or absence of aquatic insects and the amount of material deposited in the cells. Cells were divided into four groups according to the extent to which they were filled with fine sediment.

To study environmental variables influencing survival of the mussels, linear regression was used to evaluate the relationship between mortality rates of juvenile *M. margaritifera* (as mean mortality/week of exposure) during the first year of their life and the means of chemical variables (water temperature, oxygen, electric conductivity, pH, ammonia, nitrite, nitrate, orthophosphate, sodium, potassium, calcium, magnesium) calculated for each river and each interval of exposure. Data for 131 intervals, each between 6 and 12 weeks, were used.

To compare the growth of the caged mussels with that of juveniles from an undisturbed habitat, nine specimens between 4·5 and 10·3 mm length were collected during a field visit to Scotland. Individual annual growth of these mussels was determined by measuring the successive annuli of the living animals. Erosion, which usually destroys the oldest part of the shell of older mussels and thus makes it impossible to determine individual age exactly, had not yet begun in the young mussels; it was therefore possible to determine growth of the shell from the very beginning of the post-parasitic stage.

Juveniles that had been kept in river B were transferred to river A1 at the age of 13 months. In order to estimate the chances of supporting stocks in poor-quality rivers by releasing mussels that have been reared in rivers more suitable for the juveniles, survival and growth of these animals were compared prior to and after their transfer to river A1.

RESULTS

Growth and survival of cultured juveniles

Juvenile *M. margaritifera* have, to the time of writing (May 1993), been kept in cages for up to 52 months (Table 2).

A comparison of survival and growth of four populations of 460 juvenile *M. margaritifera*, each kept in different rivers of the Luneburg Heathlands, is given in Figs 2 and 3. Mortality was high during the first months of the post-parasitic stage (June until December) in all rivers examined, but was somewhat less after the first winter (Fig. 2). Differences in survival between the populations were considerable by the end of the first year. Experiments in river C had to be stopped prematurely as sand drift was so high that there was no chance of releasing juveniles into a stable sediment within this river.

Table 2. Maximum age and size of juvenile *M. margaritifera* kept in cages in four Luneburg Heathland rivers

River	Max. age (months)	Max. length of shell (mm)
A1[a]	36	2·10
A2[b]	36	6·40
B[b]	52	3·60
C[c]	23	1·40

[a]Experiments to be continued.
[b]Oldest mussels released into the sediment, to be continued with younger specimens.
[c]Experiments stopped, surviving mussels transferred to river A1.

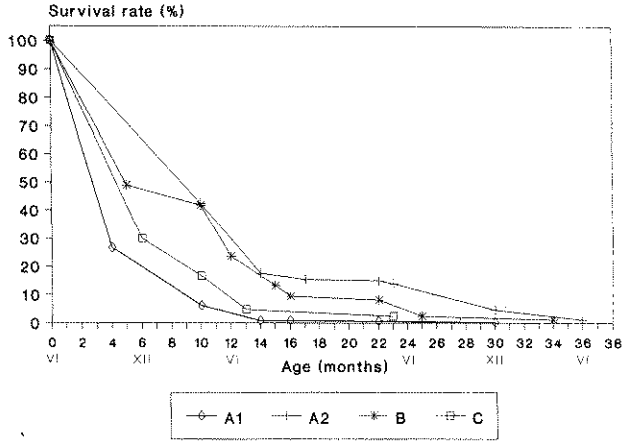

Fig. 2. Survival rates of four populations of juvenile *M. margaritifera* kept in cages in rivers of the Luneburg Heathlands.

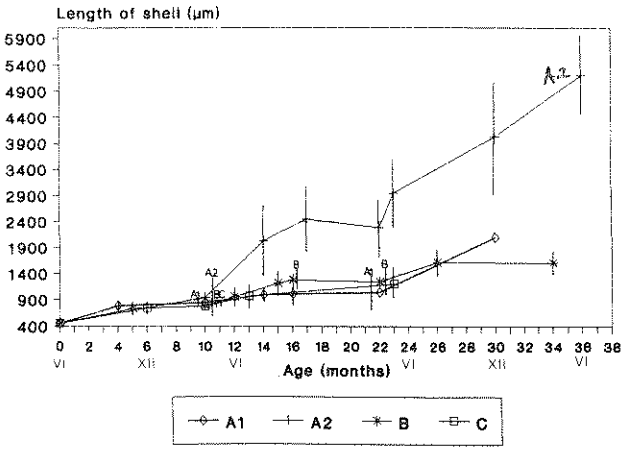

Fig. 3. Length of shell (mean and standard deviation) of four populations of juvenile *M. margaritifera* kept in cages in rivers of the Luneburg Heathlands.

Growth was markedly restricted to the warm period of the year and decreased to almost zero from October to March (Fig. 3). A reduction of the mean length of shell, as in the case of the A2 population between months 17 and 22, was due to the loss of several large individuals.

Mean growth of juveniles from the different rivers was rather uniform until the end of their first winter, although several specimens kept in A2 grew markedly faster than those in rivers A1, B or C, resulting in a higher mean length of shell for the A2 population.

Factors affecting the success of juvenile mussels

Whether juveniles survived their first winter largely depended upon their size (Table 3); 100% of the individuals <700 μm (22·8% of the total population) died during these months. Only large animals >900 μm had a 50% chance of reaching their second growing period.

Organic and inorganic material carried into the cells markedly influenced the viability of juvenile *M. margaritifera*. Table 4 shows the relationship between the amount of material deposited and the percentage of animals surviving. Cells containing moderate amounts (groups 2 and 3) had higher survival rates than those with very little or no material (group 1), but survival was lower again in cells more than two-thirds full. Only differences between groups 1 and 2 and groups 1 and 3 were statistically significant ($p<0·05$).

Cages were frequently colonised by aquatic insects, chiefly larvae of mayflies (Ephemeroptera), stoneflies (Plecoptera) and dipterans (Tipulidae, Rhagionidae, Chironomidae) and adults of aquatic beetles (Elmidae). Among these groups, chironomids occurred in 46·3% of the 1130 chambers examined. Survival rate of the mussels was 21·4% in cells colonised with chironomids, compared with 13·7% without chironomids, the difference being significant ($p<0·05$).

Growth of juvenile *M. margaritifera* from Scotland was faster than mean growth of the caged specimens (Tables 5 and 6). The largest caged juveniles grew as fast as the Scottish mussels. A few of these animals at least reached the size of the smallest specimen from Scotland; single individuals even equalled or surpassed the mean length of Scottish animals of the same age.

Comparing correlations between mortality of juvenile mussels and mean values of environmental variables from the four rivers during each period of exposure, temperature was the most consistently important factor, showing a highly significant positive correlation with mortality in three of the rivers (Table 7). It was followed by magnesium and ammonia, which both had significant positive correlations with mortality in two of the rivers. All other variables, except nitrite, which showed no significant correlation at all, were either significantly correlated in only one river or were correlated in opposite senses in two rivers.

Table 3. Survival rate of three-months-old *M. margaritifera* after seven further months of exposure in river A1

	Size class (μm)					
	<500	<600	<700	<800	<900	>900
No. of animals included	5	20	30	108	56	22
Cumulative % of the population	2·1	10·4	22·8	67·6	90·1	100·0
Survival rate (%)	0·0	0·0	0·0	3·7	7·1	45·5

Table 4. Influence of fine materials deposited in the cages upon the survival rate of juvenile *M. margaritifera*

Group[a]	1	2	3	4
Survival rate (%)	14·4	20·4	22·8	18·3

[a]Group 1, little or no material deposited; group 2, cells filled to one-third; group 3, cells filled up to two-thirds; group 4, cages filled more than two-thirds.

Table 5. Shell length of nine juvenile *M. margaritifera* from Scotland at the end of five growth periods

Specimen no.	Shell length (mm) at the end of each growth period				
	1	2	3	4	5
1	0·85	2·05	4·50		
2	1·10	3·25	5·00		
3	0·95	3·65	5·80		
4	1·15	3·50	6·00		
5	0·95	3·55	5·90		
6	1·40	2·95	4·65	8·00	
7	1·15	2·85	3·95	9·10	
8	0·85	1·80	5·80	9·00	
9	1·05	1·80	6·20	8·90	10·30
Mean length	1·05	2·82	5·31	8·75	—

Table 6. Mean and maximum of shell (mm) of caged specimens of *M. margaritifera* kept in four Luneburg Heathland rivers at the end of three growth periods

River	Length of shell (μm) at the end of growth period					
	1		2		3	
	Mean	Maximum	Mean	Maximum	Mean	Maximum
A1	0·73	1·15	1·12	1·85	2·10	2·95
A2	0·73	1·35	2·45	4·00	4·02	6·40
B	0·73	1·35	1·23	2·50	1·73	3·60
C	0·57	0·70	0·84	1·40	—	—

Table 7. Correlations between mortality of juvenile *M. margaritifera* (mean mortality/week of exposure) and means of environmental variables during time of exposure from four rivers

	River A1	River A2	River B	River C
Temperature	0·332**	ns	0·686**	0·809**
Oxygen	ns	ns	–0·434**	ns
Conductivity	–0·306*	ns	ns	0·592*
pH	ns	0·907**	ns	–0·633**
Ammonia	ns	0·710*	0·828**	ns
Nitrite	ns	ns	ns	ns
Nitrate	ns	ns	–0·355*	ns
Phosphate	ns	0·800**	ns	ns
Sodium	ns	ns	ns	0·800**
Potassium	ns	ns	–0·377*	ns
Calcium	ns	ns	ns	0·652**
Magnesium	ns	0·740*	ns	0·813**

(* $p < 0{\cdot}01$; ** $p < 0{\cdot}001$; ns, not significant).

Table 8. Correlations between growth of juvenile *M. margaritifera* (mean growth/week of exposure) and means of environmental variables during time of exposure from four rivers

	River A1	River A2	River B	River C
Temperature	0·655**	0·799*	0·406*	0·733*
Oxygen	–0·334*	–0·803**	–0·435*	ns
Conductivity	–0·587**	–0·798*	–0·409*	ns
pH	ns	ns	–0·454*	ns
Ammonia	–0·331*	ns	ns	ns
Nitrite	ns	ns	0·535*	ns
Nitrate	ns	–0·727*	ns	ns
Phosphate	–0·297*	ns	ns	ns
Sodium	0·294*	–0·769**	ns	ns
Potassium	0·469**	–0·788*	–0·357*	ns
Calcium	–0·707**	–0·796*	–0·534**	ns
Magnesium	–0·656**	–0·690*	–0·537**	ns

(* $p < 0{\cdot}01$; ** $p < 0{\cdot}001$; ns, not significant).

Calculating correlations between water chemistry variables and growth of the juvenile mussels gave results similar to those between environmental factors and mortality (Table 8). Again temperature was the most important variable, being the only one that was significantly correlated to growth in all of the rivers and, at the same time, the only variable showing any significant correlation in river C. Furthermore growth was significantly correlated to oxygen, conductivity, calcium and magnesium in rivers A1, A2 and B, while other variables were either correlated in opposite senses or correlated to growth in one river at most.

Transfer of juvenile mussels

Juvenile *M. margaritifera*, once transferred from river B to river A1, did not differ markedly from those kept in river A1 with regard to survival rate and growth (Fig. 4).

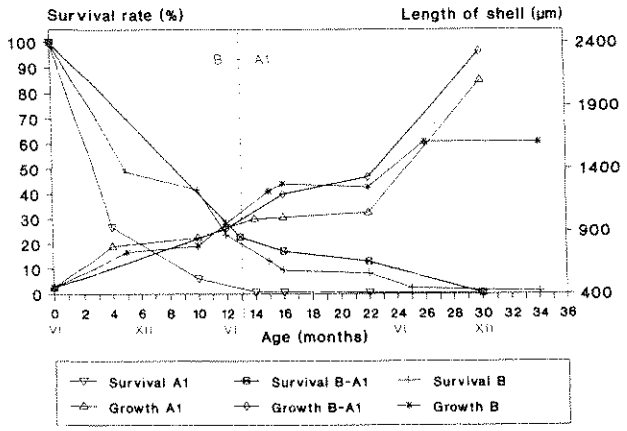

Fig. 4. Survival and growth of juvenile *M. margaritifera* prior to and after their transfer from river B to A1 (vertical line indicates the time of transfer).

DISCUSSION

Evaluation of the culture system

Any system designed for the culture of animals must aim to minimise losses and maximise the viability of the animals cultured. The cage system described above allowed juvenile freshwater pearl mussels to be kept for longer than in any previous study. Comparative data on other methods of artificial propagation do not exist. Data on the mortality of free-living juvenile unionoids are sparse and mostly based on rough estimates. Young and Williams (1984) suggest that 95% of the *M. margaritifera* that leave the host fish die before they are able to establish in the substrate, but suppose further mortality to be very low (M. Young, pers. comm.). As the percentage of cultured *M. margaritifera* that survived until the end of their first growth period (Fig. 2) was markedly higher than that predicted by Young and Williams (1984), it is concluded that the culture of juveniles can be used to increase the number of mussels that finally settle within the substrate.

A review of data on the growth of juvenile freshwater pearl mussels reveals considerable differences between several authors (Fig. 5). Comparison with my own results from Scottish juveniles shows that growth of

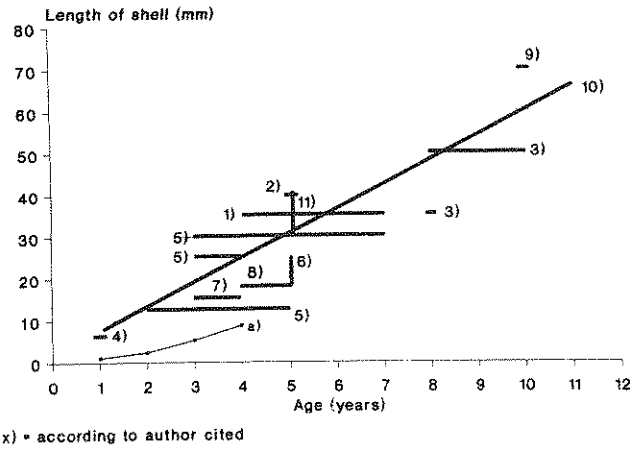

Fig. 5. Survey of growth of juvenile *M. margaritifera* as reported by several authors: (1) Altnöder (1926); (2) Boettger (1954); (3) Dyk & Dykova (1974); (4) Ekmann (1905, in Hendelberg (1961)); (5) Grundelius (1987); (6) Jackson (1925); (7) Jungbluth *et al.* (1985); (8) Jungbluth (1986); (9) Valovirta (1977); (10) Wellmann (1939); (11) Young & Williams (1984); (a) mean length of shell of Scottish sample.

young mussels at the very beginning of their post-parasitic life has generally been overestimated. Even if one considers that growth of *M. margaritifera* is strongly correlated with latitude (Bauer, 1992), the results of Jackson (1925), who investigated British populations, should allow a close comparison. In fact his results are twice as high as my own findings. A possible explanation for these differences is that corrosion of the umbo takes place at an early age in the soft waters inhabited by the freshwater pearl mussel, i.e. at about 2 cm, and so the first annuli become lost. Any determination of the age of a larger mussel is then based on the author's estimate of the time needed to build those parts now destroyed by corrosion, and is therefore unreliable.

Compared to the mean length of juvenile mussels from Scotland, the mean growth of young mussels cultured in the cage system is generally retarded (Tables 5 and 6). Only specimens kept in river A2 grew at a similar rate to those raised under natural conditions. The largest individuals from river A2 (Table 6) grew even faster than the average of the Scottish sample. Careful choice of the river is important in order to obtain optimal results in rearing juveniles.

Surprisingly, among those tested, the river with the lowest water quality allowed maximum growth and highest survival, while the other three rivers must be considered to be of equal value in the long term for culturing juvenile *M. margaritifera* despite their progressively higher water qualities.

To understand why young *M. margaritifera* thrived in slightly polluted waters, it is not before they reach a size of about 4 mm that juveniles develop a functional filtering apparatus (E. Wahlmann, pers. comm.). In the laboratory small juveniles were often observed lying among sand grains stretching out their very long versatile foot over the surface grains and retracting it into the mantle cavity, most likely to collect food particles such as microorganisms settling on the sediment. Likewise very small floating particles that crossed the edge of the valve at the anterior and the ventral side were not seen to leave the mantle chamber, and so were presumed to have been ingested.

In this way a slightly polluted river might provide more food for juveniles kept in a cage than would a river with very high water quality, although juveniles would not have been able to survive if they had settled naturally in the interstitial zone of the polluted river.

The deposition of sand within the cage system probably also improved the conditions within the cells for juveniles by increasing the surface area to be colonised by microorganisms and by filtering out particulate organic matter, both of which are consumed by the mussels (Salciute, 1984; McHenry & Birckbeck, 1985).

The positive effect of chironomids colonising the cages is most likely due to the role of faecal pellets in the nutrition of aquatic animals. Newell (1965) and Frankenberg and Smith (1967) frequently found animals feeding on faecal pellets. Shepard and Minshall (1981) compared the nutritional value of allochtonous leaf litter, epibenthic detritus and faeces. They found faecal material to be as good a food resource as the leaves and detritus, and that faecal material itself was sufficiently nutritious to maintain aquatic macroinvertebrates. In combination with the protection against displacement and perhaps also against predation, the modes of feeding observed may explain why juveniles of *M. margaritifera* spend their first few years within the sediment of the river bed.

Water quality

The physical and chemical conditions of the water influenced the viability of the juveniles, although none of the variables measured in the running water seemed to be toxic for juvenile freshwater pearl mussels within the range of concentrations encountered.

Growth and survival were predominantly negatively related to conductivity, ammonia, nitrate, phosphate, sodium, potassium, calcium and magnesium (Table 8), all of which can be regarded as indicators of eutrophication; the negative correlation between growth and oxygen is indirect, because of its dependence on temperature.

The influence of water temperature on growth of adult *M. margaritifera* has been suspected for a long time; Altnöder (1926) and Wellmann (1939) observed slower growth in the upper parts of pearl mussel rivers and increased growth downstream. Hruska (1992) found temperature to be a limiting factor for glochidial development. Nevertheless the effect of temperature is difficult to determine in field studies, as accelerated growth might be caused by direct effects of temperature on metabolism as well as by a change in food quality or uptake (Wilbur & Owen, 1964). Bauer (1992) found positive relationships between temperature, growth constant and metabolic rate of adult pearl mussels and a negative correlation between growth and eutrophication.

In river C, which had the highest water quality, growth was unaffected by seasonal changes in all variables except temperature. The increased growth of juveniles in river A2 was also probably caused by its higher water temperature rather than by increased availability of food.

The relationship between temperature and mortality is not so clear. Larger individuals have lower mortality than smaller ones but mortality increases with rising water temperature, i.e. a rise in water temperature impairs the chance of a juvenile mussel benefiting from its accelerated growth. This illustrates the delicate balance necessary for a species adapted to cold water.

Conservation measures

Artificial infection

The strategy of supporting endangered populations of *M. margaritifera* by releasing artificially infected host fish is widely accepted (Wächtler *et al.*, 1987; Bauer. 1988, 1991; Neslin & Sjuganow, 1991; Hruska, 1992) and dates back to the beginning of the century (Coker *et al.*, 1919–20; Scheuring, 1939). The number of post-

parasitic stages to be produced is mainly restricted by the number of glochidia and/or of host fish available.

In Lower Saxony, hundreds of infected fish have been released during the past 20 years. As each fish has carried up to 3000 glochidia throughout the parasitic stage, it can be estimated that some millions of juvenile mussels have been released into the interstitial zone of the rivers. However, there is no evidence that this method has led to an increased occurrence of young mussels in the local rivers.

The main disadvantages of this method are

(1) host fish will be lost during the parasitic stage of the mussel through predation or disease;

(2) others will not remain where they have been released, because suitable microhabitats have already been occupied by the local trout population;

(3) host fish will not necessarily occupy sites where the sediment is suitable for the juvenile mussels at the time of their release.

Any organisation that supports such a programme must be confident of success since several years will pass between the release of the first infected host fish and the appearance of juvenile *M. margaritifera* at the surface of the sediment.

Even so this method is widely used, as it is not very difficult from a technical point of view and can be achieved by a small group during a few weeks of the year.

The cage system

The cage system allows juveniles to be kept until they have passed a large part of their vulnerable early stages and are ready to be released into the interstitial zone. They can then be introduced directly into the best parts of the sediments using a pipe. Furthermore, juveniles can be reared in the river that is most suitable for mussel culture, and can then be transferred to another river at an age when they are viable enough to resist detrimental impacts. Finally, the results of a conservation programme are immediately verifiable by the number and size of mussels raised and released each year.

However, there are also disadvantages of the cage system:

(1) it depends upon a facility for keeping infected host fish throughout the parasitic stage of the mussel;

(2) during the period of release, trout have to be kept in suitable aquaria with sufficient water supply, allowing harvesting of the juveniles;

(3) collecting the young mussels, placing them into the cages and transferring them to the rivers requires more work than artificial infection;

(4) the routine survey of the cages (at least twice a year) involves additional effort;

(5) cages have to be cleared periodically of sand or leaves to minimise losses.

Needless to say, any strategy that supports the species only makes sense if it is performed without damage to healthy populations and is paralleled by efforts to remove those detrimental factors responsible for the original decline. This implies that no transfer of mussels from one river to another should be made unless a population is imminently threatened by physical extinction. Furthermore any conservation measures must cover the whole inhabited catchment and be directed at eliminating anthropogenic sources of fine sediments, inorganic nutrients and organic matter introduced into the river, while measures that influence the water temperature should be carefully monitored with respect to their results on the growth of the juvenile mussels.

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