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Fish and Bivalve Therapeutants in Freshwater Mussel Captive Breeding—A First Summary of Practical Experiences in European Facilities

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Abstract: A significant part of freshwater mussel populations has strongly declined and many species are severely threatened nowadays. Captive breeding programs often form a central part of conservation strategies. As the life cycles of many mussel species include an obligate parasitic phase, host fish health is a crucial component of successful mussel breeding efforts. However, information about the safe application of fish therapeutants in mussel captive breeding is scarce. This article summarizes information about practical experiences in Europe. In total, eight different therapeutants were used to treat infestations of eight pathogens. Treatment success varied depending on pathogen and prevalence when treatments were initiated. Mussels did not seem to be affected by treatments, especially as long as they remained encysted. In a second step, Virkon S was applied to treat a fungal infection in tanks with brown trout (*Salmo trutta*) carrying encysted freshwater pearl mussel (*Margaritifera margaritifera*) glochidia and to disinfect juvenile mussel rearing containers. In both cases, mussels were not harmed and treated fish fully recovered. Results indicate that certain therapeutants can be used safely and successfully at different stages of breeding cycles. Nevertheless, there is still a lack of standard protocols, which would improve efficiency and the safety of treatments.

Keywords: pathogen; host fish; freshwater mussel; excystment; fish health; juvenile mussels; parasitic phase; responsive disease treatment

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1. Introduction

Freshwater mussels are considered keystone species in a wide variety of habitats providing many valuable ecosystem services, such as water filtration, nutrient cycling or bioturbation [1–4]. Their high degree of specialization and sensitivity to contaminants and habitat alteration has made them important indicators for ecological integrity of freshwater ecosystems [5–8]. On the other hand, these features result in a strong susceptibility to habitat alteration and environmental pollution. This is especially true for unionid mussels, which often develop complex life cycles including an obligate host fish stage [8–10]. Consequently,

freshwater mussels have strongly declined over recent decades, thus becoming a highly imperiled taxonomic group [11–14].

This trend triggered extensive conservation efforts, especially in North America and Europe. As life cycles are often disrupted and populations also decline due to a lack of natural reproduction, captive breeding programs are regularly a pertinent part of conservation strategies [15,16]. Even though functional breeding protocols exist for a number of species, researchers still face several challenges. Species-dependent challenges can be related to host fish selection [17], the rearing of juvenile mussels [15,18], and the genetic structure of offspring populations [19] as well as parasite and disease issues due to stocking and relocation measures [20].

Besides selection, host fish welfare and health during the parasitic phase are a crucial factor for the successful captive breeding of unionid mussels. The host fish required for complex reproduction play a special role in the conservation efforts for mussels. The welfare of hosts must not be overlooked. As in other animal husbandry, sick animals must be given appropriate medical treatment. Treatment of fish diseases is challenging, as there are comparably few approved therapeutants for fish. In addition, it is likely that their number will be further reduced in the future due to adverse side effects for human health or the environment [21,22]. The aspect of host fish disease treatment in mussel captive breeding is strongly neglected in the literature so far in a sense that, beyond the ambition of establishing optimal rearing conditions for encysted fish and juvenile mussels, there is a lack of standard protocols for the treatment of pathogen infections. Knowledge about treatment effects on encysted glochidia or juvenile mussels remains scarce. In addition to the reduced animal welfare of the host fish, this may lead to an avoidable loss of juvenile mussels and the subsequent reduction of breeding success. The relevance of this topic increases with the duration of the parasitic phase and excystment periods. Especially, the freshwater pearl mussel (*Margaritifera margaritifera*), to which the majority of European captive breeding programs are dedicated, has an extremely long parasitic phase of up to 9 months [23].

After excystment from the host tissue, juvenile mussels may also be subject to pathogen infections. Fungal infections in juvenile mussel rearing containers can significantly reduce survival rates [15], Table 1. To date, no mussel therapeutant has been identified or is in current use in mussel captive breeding programs. So far, fungal infections are addressed through abbreviated cleaning intervals of containers and the manual removal of visibly infested individuals [24,25].

This publication therefore aims to summarize the available, but unpublished, practical experiences of using fish therapeutants in freshwater mussel captive breeding. For that purpose, experiences in European mussel breeding facilities were inquired into. Virkon S (Lanxess, Cologne, Germany) is a commercially available and widely used disinfectant, which effectively kills various pathogens. Several studies showed its applicability in fish tanks and ponds with subsequent improvement of fish health [26–28]. Therefore, a preliminary experiment investigating the reactive application of Virkon S in rearing tanks of host fish during juvenile mussel excystment and proactive use in juvenile mussel rearing containers is presented.

2. Materials and Methods

2.1. Practical Experiences of Fish Therapeutant Used in Mussel Captive Breeding Programs

A questionnaire was circulated among European mussel breeding stations in order to gather information about experiences with fish therapeutant use. The inquiry included information about:

1. Mussel species;
2. Host fish species;
3. Kind of pathogen;
4. Time of pathogen occurrence (glochidial encystment, parasitic phase, excystment phase, juvenile mussel rearing);

5. Prevalence of pathogen at time of treatment (low, medium, high);
6. Treatment (remedy, dosage, duration of application per treatment, frequency);
7. Treatment success (full recovery, low, medium, or high losses, full loss);
8. Effect on mussels (harmful, no visible effect);
9. Additional remarks.

The responses obtained are presented in a standardized format in Table 1 to allow comparison. The locations of participating breeding stations are shown in Figure 1.

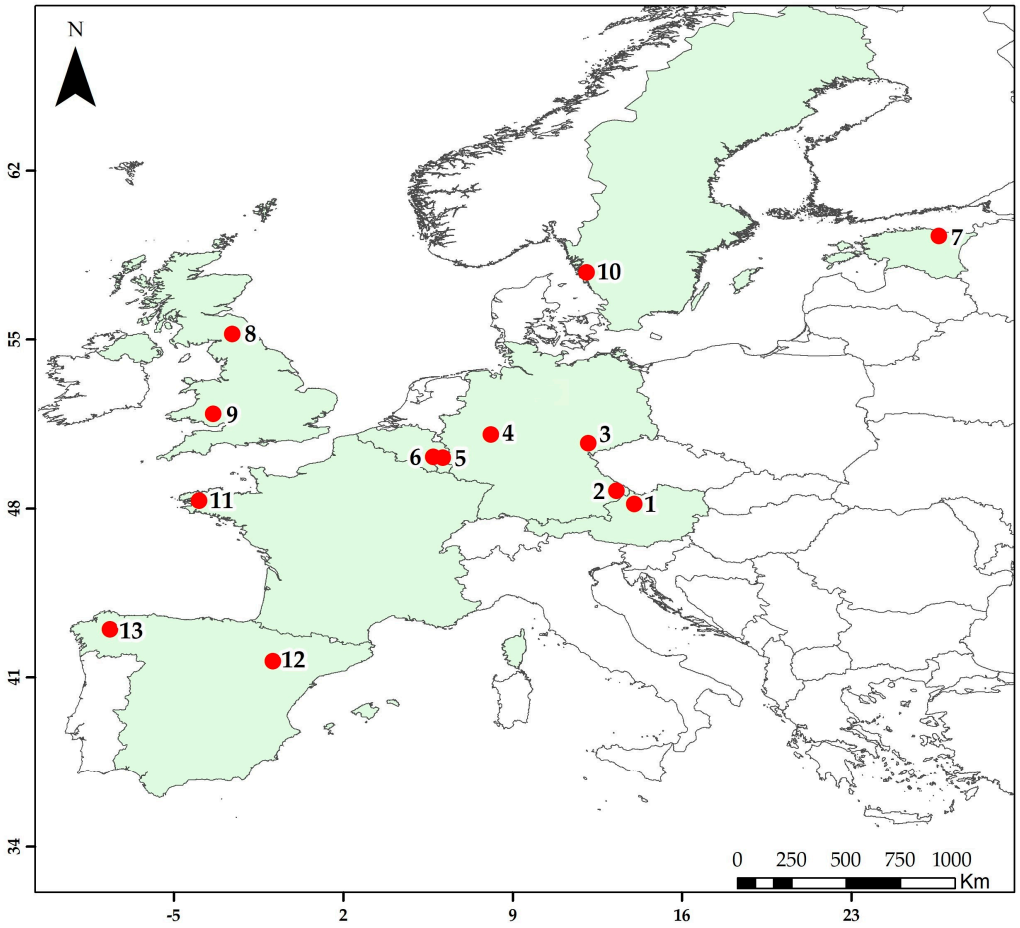

Figure 1. Location of mussel breeding stations which participated in a survey about fish therapeutant use: 1. Austria, Kefermarkt, 2. Germany, Passau, 3. Germany, Bad Elster, 4. Germany, Albaum, 5. Luxembourg, Kalborn, 6. Belgium, Wallonie, 7. Estonia, Polula, 8. England, Kielder, 9. Wales, Cynrig, 10. Sweden, Gothenburg, 11. France, Brasparts, 12. Spain, Zaragoza, 13. Spain, Lugo.

2.2. Application of Virkon S in Fish and Juvenile Mussel Rearing Tanks

In both experiments described below, Virkon S was applied at a concentration of 4 ppm for tank disinfection, which is known to successfully inhibit Saprolegnia growth and to be tolerable to fish [27]. Two tests were carried out:

1. Reactive treatment: Eight brown trout (*Salmo trutta*) during juvenile mussel excystment were reared in four standard 60 L glass aquaria. Each aquarium was separated into two compartments by a filter mat and stocked with two brown trout. Water was supplied from a pearl mussel stream and filtered over a 100 µm mesh before use. Water was recirculated with an exchange rate of 20% 1–2 times weekly. The water temperature was kept at 18 °C. Four fish in two aquaria exhibited symptoms of fungal skin infections, which was an opportunity for a preliminary test on the effect of Virkon S use for disinfection during juvenile mussel harvest. In these tanks, Virkon S was added to the water for 15 min on 3 consecutive days and on day 5. After each

application, 80% of the water was exchanged and discarded into the sewage system. The two other aquaria with 4 healthy fish served as a control. During the complete excystment period, juvenile mussels were harvested daily and samples were checked for dead specimens. Furthermore, juvenile mussel survival and growth rates were monitored for a three-month period. Fish survival was followed up for one month after the treatment.

2. Pro-active treatment: Six replicate rearing containers (Regalux clear box mini, Bahag AG, Mannheim, Germany) were set up, each with 10 juvenile, pedal-feeding freshwater pearl mussels. Juveniles had been reared for about four weeks after excystment to ensure only vital individuals were included. Three containers were treated twice with Virkon S on the first and third day of the experiment with an exposure lasting 15 min. The water was then completely changed but before use it was filtered through a 100 µm mesh. The other three replicates served as a control. In all containers, juvenile pearl mussels were fed with detritus, Nanno 3600® and Shellfish diet 1800® (both Reed Mariculture, Campbell, CA, USA), which were added at a concentration of 0.2 ppt each. Both groups were followed up for three months. Food and water were renewed every five days. Survival and growth rates between the beginning and the end of the experiment were calculated. The temperature was kept between 18–19 °C.

Differences between treatments were investigated using two-tailed *t*-tests, after checking the homogeneity of variances using Levene tests. Tests were performed using R statistical software version 3.4.0 [29].

3. Results

3.1. Practical Experiences of Fish Therapeutant Used in Mussel Captive Breeding Programs

Questionnaires were returned from 13 out of 22 contacted mussel breeding facilities. Although the majority of answers were related to freshwater pearl mussel with brown trout or Atlantic salmon (*Salmo salar*) as a host, these results cover ten countries and four species of freshwater mussels including the critically endangered mussel *Pseudunio auricularius* (Table 1). Eight fish pathogens were observed, which belonged to bacteria such as *Aeromonas* sp. and *Flavobacterium* sp., protozoans such as *Dactylogyrus* sp. and *Trichodina* sp. and fungi such as those of the genus *Saprolegnia*.

Handling of encysted fish stocks varied strongly between breeding stations. There is no discernible pattern relating the use of certain therapeutants to geographic location or facility type. In five breeding facilities, distributed over four countries, encysted host fish stocks were not treated with any therapeutants at all, but losses should be prevented exclusively by the optimization of rearing conditions. Two of these facilities are located in Germany. The others are located in France, Belgium and Estonia. In Austria, no therapeutants were used for encysted host fish but single, strongly infested individuals were removed from tanks. In three breeding facilities, one therapeutant was used (Sweden and Spain; in Austria, only before glochidial encystment). In four stations distributed across Spain, Germany, Wales and England, two different therapeutants were applied. The only breeding facility using three therapeutants was located in Luxembourg. Therapeutants were always used separately and no treatment combinations were reported.

Table 1. Experiences with fish therapeutant used in 13 European freshwater mussel breeding facilities distributed over 10 countries (Austria 1, Germany 2,3,4, Luxembourg 5, Belgium 6, Estonia 7, England 8, Wales 9, Sweden 10, France 11 and Spain 12,13; approximate locations of breeding stations are shown in Figure 1) treating host fish infected by various pathogens.

Breeding Facility	Mussel Species	Host Fish Species	Pathogen	Occurrence Time	Prevalence at Time of Treatment	Treatment	Treatment Success	Effect on Mussels	Additional Remarks
9	*Margaritifera margaritifera*	*Salmo trutta/Salmo salar*	Fungal infection	Glochidial encystment	medium	clay 1 kg/m^3	high	no	
13				Parasitic phase	low	Formaldehyde 35–38%, 250 ppt for 30 min, 2 days, 2 days rest, 1 day	high	no	
2				Parasitic and Excystment phase	low–medium	Salt, 2% for 20–30 min, 5 days	high	no	early application increases success
10					low	salt, different concentrations	high	no	
2						4 g/m^3 Virkon S, 3 days, 1 day pause, 1 day treatment	full recovery	no	
9	*Margaritifera margaritifera*	*Salmo trutta/Salmo salar*	*Ichthyobodo necator*, *Trichodina*	Glochidial encystment	medium	Formalin 1:5000	high	no	Do not use near to excystment
5, 8			*Ichthyobodo necator*	Parasitic and Excystment phase	low–medium	Salt, 2%, 60 min, up to 3 times per week	high–full recovery	no	
8						Pyceze, 20 ppm	full recovery	no	
5			*Trichodina* sp.	Parasitic and Excystment phase	medium	Salt, 2%, 60 min, up to 3 times per week	high	no	
13			*Ichthyobodo necator*		low	Formaldehyde 35–38%, 250 ppt for 30 min, 2 days, 2 days rest, 1 day	medium	no	Treatment eliminates pathogen, but lesions in fins remain
5	*Margaritifera margaritifera*	*Salmo trutta/Salmo salar*	*Dactylogyrus* sp.	Parasitic and Excystment phase	low	Salt, 2%, 60 min, up to 3 times per week	high	no	
5	*Margaritifera margaritifera*	*Salmo trutta/Salmo salar*	*Aeromonas salmonicida*	Parasitic phase	high	florfénicol 20 mg active substance/kg fish/day, for 10 days; -> Nuflor® 300 mg florfénicol, oral, 1 mL/15 kg fish/day for 10 days, mixed with food	high	no	
13					low	Formaldehyde 35–38%, 250 ppt for 30 min, 2 days, 2 days rest, 1 day	medium		

Table 1. *Cont.*

Breeding Facility	Mussel Species	Host Fish Species	Pathogen	Occurrence Time	Prevalence at Time of Treatment	Treatment	Treatment Success	Effect on Mussels	Additional Remarks
5	*Margaritifera margaritifera*	*Salmo trutta/Salmo salar*	*Scyphidia* sp.	Parasitic and Excystment phase	medium	Salt, 2%, 60 min, up to 3 times per week	high	no	
5	*Margaritifera margaritifera*	*Salmo trutta/Salmo salar*	*Flavobacterium* sp.	Parasitic phase	high	chloramin- T; bath, dosage dependend on pH: low pH, low dosage. pH +/− 7: 6 g/m^3 for 60 min 1–2 times /day for 3 days, after that every 2 days for 3 treatments, after that every 3 days for another 3 treatments. Dosage can be lifted to a maximum of 15 g/m^3	full recovery	no	
5				Parasitic phase	high	florfénicol 20 mg active substance/kg fish/day, for 10 days; -> Nuflor® 300 mg florfénicol, oral, 1 mL/15 kg fish/day for 10 days, mixed with food	high	no obvious effect	
2				Excystment phase	low-medium	4 g/m^3 Virkon S, 3 days, 1 day pause, 1 day treatment	high	no	
2	*Margaritifera margaritifera*	*Salmo trutta/Salmo salar*	*Ichthyophtirius multifiliis*	Excystment phase	medium–high	Salt, 2% for 20–30 min, 5 days	low–medium	no	
2				Excystment phase	medium–high	4 g/m^3 Virkon S, 3 days, 1 day pause, 1 day treatment	high	no	
1				Glochidial encystment	high	Acetic acid, ppm in flow-through tanks once a day for 3 days	full loss		pathogen pressure probably already too high in combination with high water temperature
1	*Margaritifera margaritifera*	*Salmo trutta*	different ectodermal pathogens	Glochidial encystment, excystment	low	Removal of infected fish/fish with unusual behavior, disinfection of tanks during glochidial encystment	high	no	
12	*Pseudunio auricularius*	*Salaria fluviatilis*	*Ichthyophtirius multifiliis*	Glochidial encystment, Parasitic phase	high	Salt baths (1–3% salinity), 30 min	medium	no	
12	*Pseudunio auricularius*	*Acipenser baeri*	no pathogens detected yet						

Table 1. *Cont.*

Breeding Facility	Mussel Species	Host Fish Species	Pathogen	Occurrence Time	Prevalence at Time of Treatment	Treatment	Treatment Success	Effect on Mussels	Additional Remarks
12	*Potomida littoralis*	*Barbus graellsi*	Fungal infection	Before glochidial encystment	high	Acriflavine + sulfate and copper chloride	low-medium	not assessed	
3, 4, 6, 7, 11	*Margaritifera margaritifera*	*Salmo trutta/Salmo salar*				No treatment in parasitic and excystment phase			
5	*Unio crassus*	*Phoxinus phoxinus*				No treatment in parasitic and excystment phase			

Deployed therapeutants had different modes of action. Some, such as Virkon S, chloramine-T, acetic acid, acriflavine or formaldehyde belonged to disinfectants aiming at the elimination of pathogens in the environment, i.e., in water and on surfaces. Clay, in contrast, can bind to certain pathogens and prevent attachment to the fish, thereby reducing virulence without harming the pathogen. The treatment success of both variants was mainly high, except for acetic acid used against *I. multifiliis* in Austria. Antibiotics are designed to eliminate pathogens in sick specimens supporting the hosts' immune response. The only applied antibiotic was florfenicol. It was used successfully against *Aeromonas salmonicida* and *Flavobacterium* sp. in Luxembourg. The most commonly applied therapeutant was salt, which increases mucus production of the fish skin and thereby increases shedding of attached ecto-pathogens. Salt baths were applied in different concentrations and treatment durations against six different pathogens (Table 1) and in five facilities. Salt was the least specifically used therapeutant and was also applied in different treatment regimes, i.e., durations or concentrations. For some pathogens, various therapeutants were applied belonging to different agents. For instance, fungal infections were treated with clay, formaldehyde, salt, Virkon S and acraflavine. All of them were assessed to have high treatment success up to full recovery of fish, except for acraflavine, which was evaluated as having low–medium success. In contrast, infestations of *Scyphydia* sp. and *Dactylogyrus* sp. were exclusively treated with salt. It is noteworthy that some pathogens were more common than others. The latter were only reported from Luxembourg whereas fungal infections occurred in the majority of breeding facilities. *I. mutlifiliis* and *I. necator* infestations were also reported several times.

3.2. Application of Virkon S in Fish and Juvenile Mussel Rearing Tanks

Host fish recovered completely from fungal infections after Virkon S application. All brown trout in treatment and reference tanks were alive and healthy one month after the treatment. The juvenile mussel harvest varied slightly between groups with 313 and 365 juveniles per host fish in the treatment and control group, respectively (Table 2). In both groups, excystment started at the same time and no empty shells were discovered in the harvested samples. Survival was extremely high at more than 90%. Shell lengths were equal in both groups with a mean of 1.5 mm after three months. Slight differences in the number of harvested juveniles are most likely to be attributed to differences in the glochidial encystment rates of host fish specimens instead of being caused by Virkon S application. Results indicate that treatment of fungal skin infections by Virkon S application in rearing tanks is effective and does not impair juvenile mussel excystment.

Table 2. Juvenile mussel performance during reactive treatment with Virkon S in aquaria for juvenile mussel harvest. Two encysted brown trout were reared per aquarium.

	Treatment		**Control**	
	Aquarium 1	**Aquarium 2**	**Aquarium 1**	**Aquarium 2**
Mean number of juvenile mussels harvested per fish.	295	331	395	335
Total number of juvenile mussels after harvest.	590	662	790	670
Total number of juvenile mussels after 3 months.	544	601	737	622
Survival rate in % after 3 months.	92	91	93	93
Average shell length in mm after 3 months.	1.56	1.48	1.52	1.56

Juvenile mussels in the control group and those exposed to Virkon S almost had the same shell length when the experiment was started, with 0.56 and 0.58 mm in the control and treatment group, respectively. After three months, differences in shell length were

more pronounced with 1.76 and 1.59 mm in the control versus the treatment group, even though the two-tailed *t*-test did not prove to be significant ($p = 0.1142$) (Figure 2). However, differences between average growth rates were significant (two-tailed *t*-test, $p = 0.03201$). Nevertheless, growth rates in both cohorts must be considered high with an average of 221% in the control and 176% in the treatment group, respectively. Survival was slightly lower in the treatment group with 83% compared to the control with 90% (two-tailed *t*-test, $p = 0.3739$).

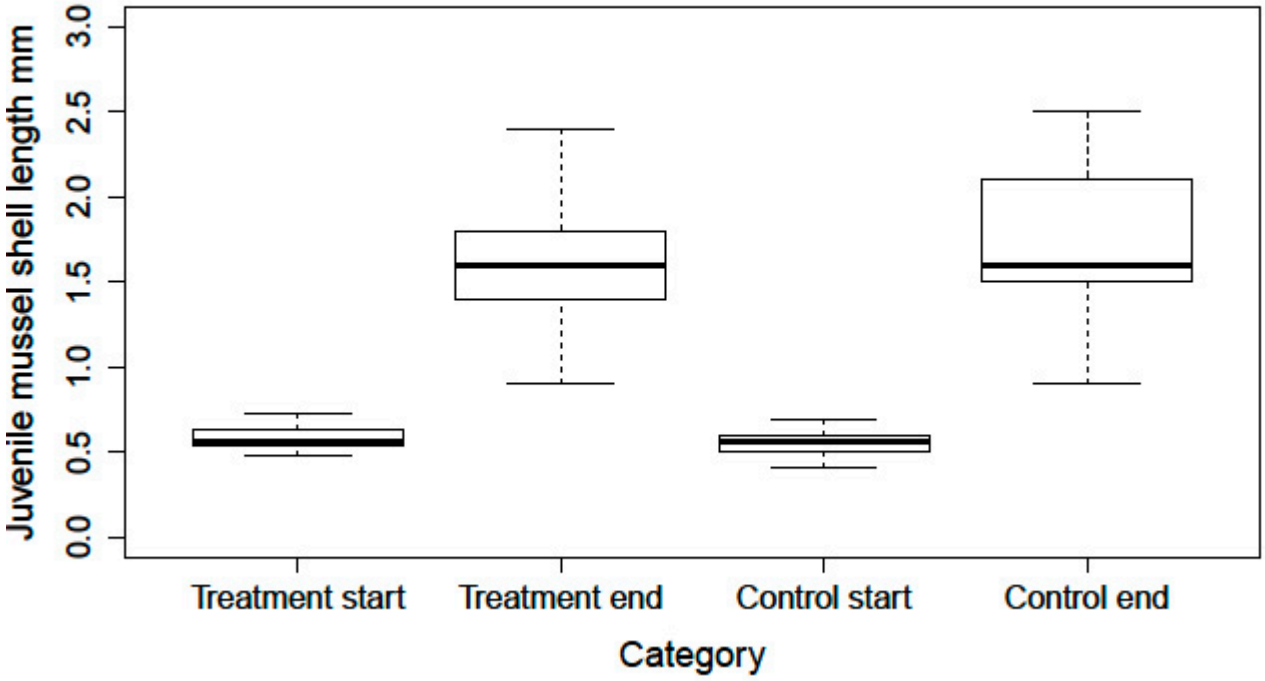

Figure 2. Boxplots of freshwater pearl mussel (*Margaritifera margaritifera*) juvenile shell length at the beginning and three months after Virkon S application in treatment ($n_{start} = 30$; $n_{end} = 25$) and control groups ($n_{start} = 30$; $n_{end} = 27$) of the proactive treatment in juvenile mussel rearing tanks.

4. Discussion

Captive breeding of endangered freshwater mussel species is a tool often applied for short-term conservation of strongly depleted populations and species [15–19,30]. Many freshwater mussel species spend an obligate parasitic phase on a host fish [31]. Standards for animal welfare must be respected for the host fish, not least because of their importance for the successful reproduction of the target species. The promotion of fitness and reduction of stress levels via the optimization of rearing conditions are the basic components of fish welfare. Necessary measures vary, e.g., depending on the technical setup, fish species and origin or water source. For example, mussel excystment facilities may run as recirculation or flow-through systems utilizing groundwater or lake/stream water supplies. Therefore, different filter systems, UV disinfection, the heating or cooling of water and water exchange intervals may be central parameters shaping water quality which keep entry rates of pathogens and parasites low. There are also differences in territoriality and in susceptibility to handling and rearing stress between fish species and if the fish comes from the wild or hatchery. As in the case of *P. auricularius* captive breeding, where Siberian sturgeon (*A. baeri*) from hatchery is generally used, the fish are adapted to the manipulation and the type of food, resulting in the non-appearance of diseases during the breeding period. Unlike the river blenny (*S. fluviatilis*), which comes from the wild, and which in more than 90% of cases, develops *I. multifiliis* infestations. Thus, factors like shelter structures, light intensity and fish density need to be adapted. However, optimized rearing conditions may not always be sufficient to keep host fish completely healthy. Fish health issues are mainly associated with increased stress levels such as those caused by high water temperatures. Higher water

temperatures may increase the prevalence of infection in various diseases [32]. For example, fish infection outbreaks often coincide with juvenile pearl mussel excystment, affecting a sensitive phase of the reproductive cycle. Options for the amelioration of rearing conditions are limited in this phase of the life cycle, as threshold temperatures are usually necessary to trigger and synchronize juvenile mussel excystment. In addition, glochidial encystment in fish tissues could be an entry route for opportunistic pathogens, which take advantage of this inflammation of the gill epithelium as an access to the fish [33]. Consequently, pathogen control and treatment of infections are relevant topics in mussel breeding programs. Their significance may further enhance, as rising water temperatures due to global warming likely lead to an increase in the virulence of pathogens and temperature stress—especially for cold water fish such as brown trout [32]. However, it is well-known that juvenile mussels and glochidia are highly sensitive and may be harmed by commonly used fish therapeutants or disinfectants such as salt [5,34,35].

Despite that relevance, mainly anecdotal and unpublished knowledge on pathogen treatment options in mussel breeding programs exist. Standard procedures are still lacking. In our survey, this is illustrated by both the strong variability of therapeutants and treatment regimes for certain pathogens as well as the application of unspecific therapeutants aiming at general pathogen reduction in the environment and support of fish immune response rather than specific elimination of a certain pathogen. Treatment options for fish diseases are limited compared to many other species because of economic, legal and environmental requirements [22,36]. These challenges are aggravated in the case of mussel breeding programs by the fact that mussel and glochidial sensitivity to therapeutants are often unknown or known to be harmful. These circumstances make it seem likely that the different management of fish diseases observed in our study is caused by individual attitudes towards therapeutant use in general and/or the degree of precaution of responsible breeders who do not want to lose a complete cohort of juvenile mussels by using potentially harmful host fish treatment instead of an overriding geographic pattern. This is further corroborated by the fact that, e.g., neighboring breeding facilities in Belgium and Luxembourg did not apply therapeutants to encysted fish at all or applied the highest number of different therapeutants in our survey, respectively.

Probably the only example of a standardized experiment is the study by Rach et al. [37], in which largemouth bass encysted with glochidia of the plain pocketbook mussel were systematically exposed to five different therapeutics, which obviously did not impair the transformation success of juvenile mussels. Treatment with the therapeutants listed in our survey also did not seem to harm encysted glochidia. However, treatment success was not always satisfying. Our preliminary data point to a prominent role of pathogen prevalences when treatments are started as success was low mainly in cases of high prevalence (Table 1). However, it remains unknown whether a different treatment regime or application of another therapeutant might have produced a different result. Based on our survey, salt baths used during the parasitic and excystment phase are the most common treatment for various pathogens in European breeding facilities. Salt seems to be harmless to mussels as long as they are still encysted by fish epithelia. It is useful to support mucus production in fish skin and is effective at curing local infections of injuries. In addition, salt is cheap, non-toxic to humans, easy to apply and does not require specific permissions or storage conditions, as many other substances do. However, some shortcomings should not be overlooked: The treatment success of salt depends on pathogen prevalence and pathogen species. Furthermore, it is inapplicable in rearing tanks which also contain free juvenile mussels or glochidia. Variability in treatment methods and their success further underlines that standard protocols are missing, which, if they existed, would help to improve fish health and consequently increase the success of mussel breeding efforts. Thus, extended options, as indicated in our survey, are necessary to effectively reduce the presence of pathogens. The development of standard protocols and tests involving different fish and mussel species is strongly recommended to improve handling of pathogen infections and avoid unnecessary losses in breeding cycles.

Therefore, the applicability of Virkon S was tested for disinfection of rearing tanks of encysted fish and freshly excysted, i.e., pedal-feeding, juvenile mussels. Slightly lower growth and survival rates of juvenile mussels in the treatment group were observed. These variances between treatment and control group were lower than those which are often observed between different containers in the standard breeding process. Consequently, it remains unclear whether variances show a slight impairment of juvenile mussels due to Virkon S application or if this is an accidental observation. A clear advantage of Virkon S compared to salt is the stronger disinfectant effect and its applicability within the rearing containers, thus ameliorating pathogen suppression. These results, though preliminary, suggest that Virkon S may be successful as a disinfectant supporting biosecurity plans in mussel breeding stations, and also as a proactive and reactive treatment in fish and mussel tanks. However, before clear recommendations can be expressed, extended tests, with an increased number of at least three replicates, are necessary. These tests should investigate the effects of Virkon S after more frequent application, at different water temperatures, on other mussel species and at other life stages, e.g., filtering juvenile mussels. Additionally, careful consideration of the disposal of treated water should be ensured to avoid any negative impact on potentially connected habitats.

5. Conclusions

We have summarized information about experiences in host fish disease treatments from 13 European mussel breeding stations. Several treatments successfully curing fish diseases which seem to be harmless for mussels could be identified. However, some therapeutants were used inconsistently and with varying treatment success pointing to the necessity to elaborate knowledge on host fish treatments in mussel breeding programs, to develop standard protocols further increasing the efficacy of therapeutants used and to establish threshold values that are safe for encysted glochidia. No treatment options are available for juvenile mussels so far. Our preliminary results on the application of Virkon S in rearing containers are encouraging and should also be followed up to establish threshold values for concentrations and application frequencies. Tests need to be extended to other species and age classes.

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