ISSN 1062-3590, Biology Bulletin, 2017, Vol. 44, No. 1, pp. 61–66. © Pleiades Publishing, Inc., 2017.

CONFERENCE MATERIALS

The Freshwater Pearl Mussel *Margaritifera margaritifera* in Bavaria, Germany—Population Status, Conservation Efforts and Challenges[1]

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Received February 11, 2016

Abstract—The freshwater pearl mussel *Margaritifera margaritifera* is a highly specialized, sensitive and critically endangered freshwater bivalve with a complex life cycle. An overview on the population status in Bavaria, Germany, one of the species' main areas of distribution in Central Europe, is presented. Using the example of the freshwater pearl mussel and a Bavarian conservation project for this species, a scheme for the development of site-specific conservation concepts is discussed.

DOI: 10.1134/S1062359017010034

INTRODUCTION

The freshwater pearl mussel *Margaritifera margaritifera* is a highly specialized and sensitive freshwater mussel with a complex life cycle. It inhabits clean and cool salmonid streams in the northern hemisphere (Hastie et al., 2000; Geist and Auerswald, 2007; Geist, 2010). The species' life cycle includes an obligate parasitic stage on a suitable host fish, which is either Atlantic salmon (*Salmo salar*) or brown trout (*S. trutta*) (Young and Williams, 1984; Geist et al., 2006; Taeubert et al., 2010). After the drop-off from the host, juvenile mussels spend several years in the interstitial zone. Several studies demonstrated that the juvenile stage is the most sensitive life stage, being strongly affected by river substrate degradation due to increased fine sediment introduction to the interstitial zone (Geist and Auerswald, 2007; Österling et al., 2008; Denic and Geist, 2015; Scheder et al., 2015). Low recruitment success due to this problem resulted in strong population declines, with many populations now being at the brink of extinction (Geist, 2010; Gum et al., 2011).

At the same time, the key role of functional river substrata and functionally intact *M. margaritifera* populations in the context of healthy river ecosystems is increasingly being recognized. As a consequence, intensive research and restoration efforts to improve stream habitats and restore substratum quality have been launched (Malcolm et al., 2004; Dudgeon et al., 2006; Greig et al., 2007; Palmer et al., 2014). However, restoration success is often still low due to various reasons. First, species such as the freshwater pearl mussel slowly react to changes. Consequently, reactions are detectable only with a remarkable time lag of several years, due to low growth rates and the long life span. Second, though the reasons for declines are similar throughout the distribution range, many factors influencing the population and restoration success vary considerably, such as landscape, topography, river size, catchment structure or social structure and density of the human population, making the application of one universal restoration approach almost impossible.

In this article, we give an overview on the status of *M. margaritifera* in Bavaria, Germany, where the majority of Central European populations are located. In a second step, we present a generally applicable concept for the development of site-specific solutions in nature conservation using the example of *M. margaritifera* conservation in Bavaria, and a recently launched conservation project as a role model (ArKoNaVera-Subproject E: Rescue of the Freshwater Pearl Mussel in Lower Bavaria).

POPULATION STATUS OF *M. margaritifera* IN BAVARIA, GERMANY

The distribution of *M. margaritifera* populations in Bavaria is naturally restricted to the Eastern area along the borderline between Germany and the Czech Republic where siliceous geology prevails (Fig. 1). At present, a total of 46 populations are known in Bavaria with a size of 5–30000 individuals per population, and 80000–90000 individuals in total. Compared to 1859, when Von Hessling (1859) counted 130 pearl mussel populations in Bavaria, more than half of the populations have gone extinct. With respect to the number of

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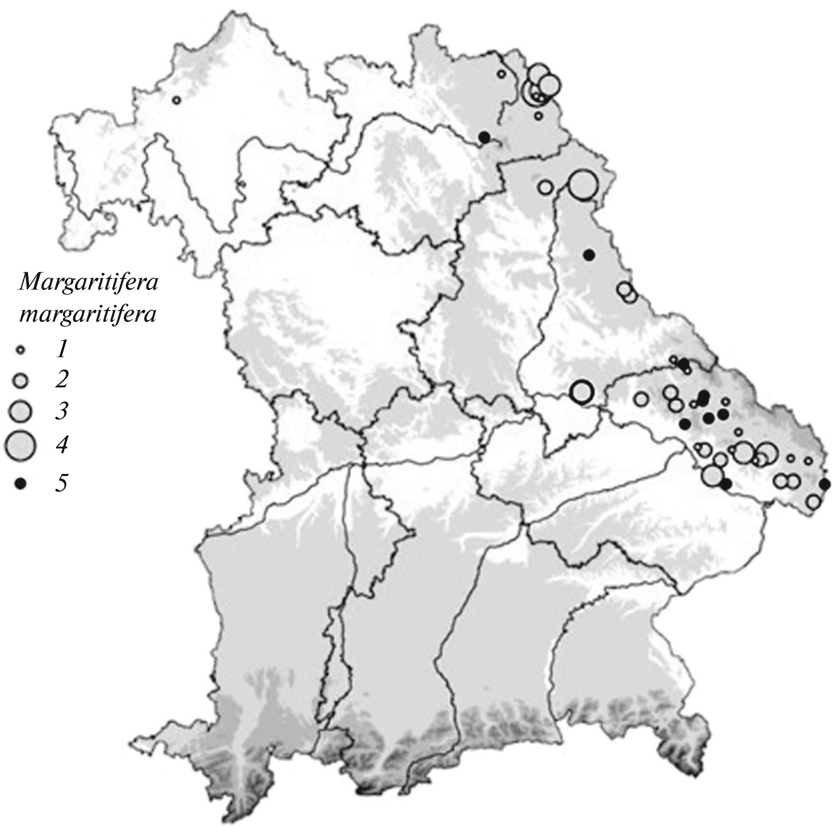

Fig. 1. Pearl mussel, *Margaritifera margaritifera,* distribution in Bavaria, Germany. Number of mussels: (*1*) <100, (*2*) <1000, (*3*) <10 000, (*4*) >10 000, (*5*) unknown.

specimens, an even more drastic loss of more than 90 percent compared to Von Hessling is estimated. Furthermore, only two populations comprise about two thirds of individuals presently, whereas the majority of populations are small, relict populations with less than 100 specimens that have lacked successful recruitment for several decades (Fig. 2). Natural recruitment still occurs in 9 populations. Yet, recruitment rates are too low to keep up a stable population size, or increase the number of individuals, as even these populations are dominated by older individuals with an age of at least 40 years (Data from the Bavarian Mussel Coordination Office).

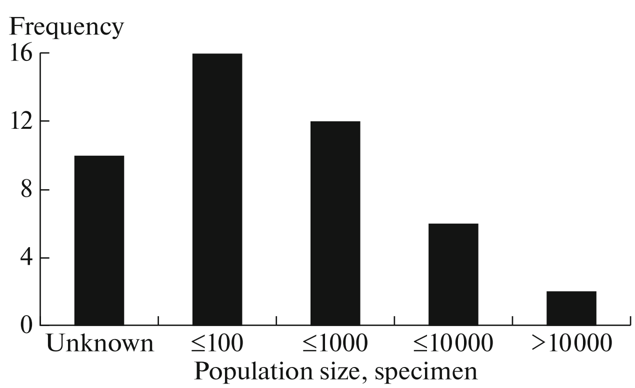

Fig. 2. Population size-frequency distribution of Bavarian *Margaritifera margaritifera* populations.

These facts illustrate that the remaining time for a successful conservation of the freshwater pearl mussel in Bavaria is short, despite of the species' long life span. As a result, a new conservation strategy has been implemented in Bavaria since 2009. As a first step, populations were prioritized according to population size, age, genetic structure, habitat quality and restoration perspectives of rivers and their catchments. Conservation action now primarily focuses on the streams with the best rating in this prioritization process, mainly comprising rivers that host at least 1000 individuals and those where natural recruitment can still be observed. For these populations, a dual conservation strategy was set up, consisting of habitat restoration measures as a long-term goal, and captive breeding as an emergency tool to conserve the genetic and evolutionary potential. Though this strategy applies all over Bavaria, it does not and cannot provide methodological solutions for the specific deficits and problems of single rivers, mostly because of the vast variety of influences and interactions among different factors shaping the structure of rivers and their catchments.

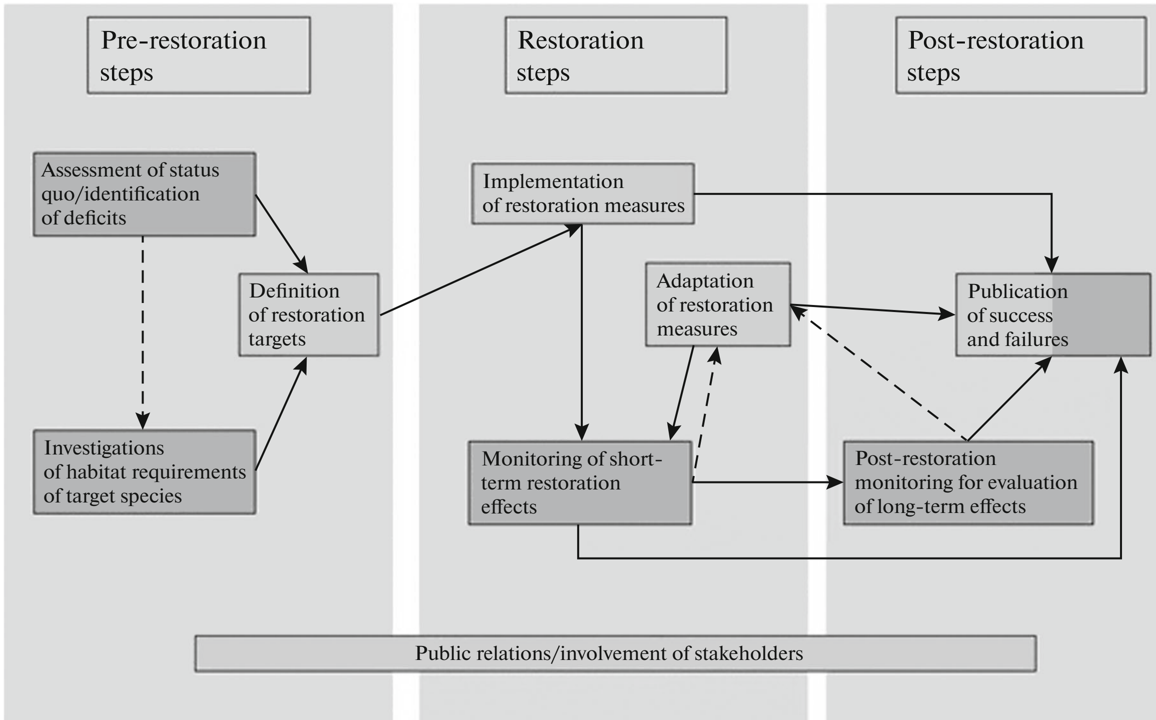

Fig. 3. Restoration project scheme; dark grey boxes represent research steps and light grey boxes represent practical conservation steps; drawn through lines are obligate and dashed lines are optional pathways.

For instance, among many other factors, catchment size of Bavarian pearl mussel rivers varies by a factor of 100. As a consequence, specific solutions for every river need to be developed, whereas, at the same time, there are some basic steps, which are required in every conservation project (Palmer et al., 2005; Geist, 2010, 2015; Malcolm et al., 2012; Nislow and Armstrong, 2012).

A GENERAL CONCEPT FOR INDIVIDUAL SOLUTIONS

There is still a trend to neglect the development of site-specific conservation concepts and consequent monitoring programs of conservation success (Greig et al., 2005; Malcolm et al., 2012). In more than half of the restoration projects carried out in the U.S., the absence of measurable objectives complicates an assessment of project success (Bernhardt et al., 2007; Kondolf et al., 2007). In addition, practitioners often lack methodological, financial and personnel resources for the implementation of adequate monitoring programs (SER, 2004). Indeed, several examples in the literature show that the assessment of restoration success is difficult already starting with the definition of success. Frequently, the success of ecologically motivated projects is evaluated by public opinion and post-project appearance, parameters which are not related to ecology (Bernhardt et al., 2007). Furthermore, the analysis of different parameters or endpoints may produce contradictory results concerning success/efficiency of specific restoration measures (Lepori et al., 2005; Mueller et al., 2014). As a consequence, Mueller et al. (2014) propose a multi-scale evaluation concept.

Figure 3 illustrates a basic scheme for the development of individual conservation concepts, incorporating ideas and experiences from other studies. In the following paragraphs, we will present a case-related concretization of this scheme using pearl mussel conservation, in particular the project "ArKoNaVera-subproject E, Rescue of the freshwater pearl mussel in Lower Bavaria" launched in May 2015, as an example.

THE PRE-RESTORATION PERIOD

Every conservation project can be divided into three main periods, the pre-restoration, restoration and post-restoration period. During the pre-restoration period, site-specific conservation and monitoring concepts need to be developed, based on detailed information on the present status of target species and their habitats, ideally incorporating different scales from micro- to macrohabitats and from the individual life stage to the species, or even community level. In case of ArKoNaVera, this basic knowledge was already gathered in the course of regular monitoring action such as Natura 2000 and European water framework directive monitoring, and pearl mussel research projects (Geist and Auerswald, 2007; Vandre et al., 2010;

Overview on the abiotic and biotic components of the monitoring program in the project ArKoNaVera-subproject E

Abiotic components		Biotic components	
Water quality	Nitrogen components	Mussel population	Age structure
	Phosphorous	Host fish	Density–age structure
	Electrical conductivity		
	Dissolved oxygen	Bioindication with juvenile mussels	Density
	Water temperature		Survival
	Turbidity		Growth rate
Hydromorphology	Flow		
	Substrate composition		
	Substrate stability		

Kuehn et al., 2011; Denic et al., 2015). The main deficits identified in the project area are increased introduction of sand and silt from intensive land use far beyond natural background levels, alteration of water flow regimes and habitat fragmentation due to damming. It has to be stressed that in case of the pearl mussel, whose life cycle directly depends on the presence of its host fish, an assessment of the condition of host fish populations has to be an integral component of deficit analyses. As a result of deficit analyses and the definition of reference conditions, clear and measurable project aims need to be set in advance of restoration action and should ideally comprise both scientific and outreach elements. The specific project aims in ArKoNaVera are: support of pearl mussel populations by captive-breeding, at least doubling the number of individuals by the end of the funding period; creation of river sections with suitable habitat quality for reintroduction of juvenile mussels and natural recruitment; increase of public awareness and installation of a local conservation network in the project area.

THE RESTORATION PERIOD

During the restoration period active restoration steps and monitoring of restoration effects are carried out. Monitoring should follow the BACI design. Therefore, if pre-restoration data are unsuitable as before impact data sets, sampling needs to be the first working step in the restoration period. Both aspects, restoration and monitoring, need to be adjusted not only to the local field situation, but also consider project features such as funding volume and project duration. The latter often reduce projects to mere restoration action without any monitoring (SER, 2004; Wurfer et al., 2015). In such cases, post-project monitoring possibilities should be checked and created already during project planning. In the ArKoNaVera-project, the next step is going to be the before impact monitoring at specific restoration sites comprising various parameters and endpoints (table), as this is known to increase reliability of monitoring results (Ruiz-Jaen and Aide, 2005).

Successful restoration action often consists of a mix of different measures. To mitigate the current main problem, i.e., sedimentation, this particularly involves the combination of land use extensification, the creation of buffer zones, installation of sediment traps, and other improvements of habitat structure. At this level, the impact of measures on adjacent areas has to be considered following guidelines (Palmer et al., 2005). Accordingly, “during the construction phase, no lasting harm should be inflicted on the ecosystem.” Substratum raking proved to adversely affect downstream river sections (Sternecker et al., 2013; Mueller et al., 2014) and such possible negative effects need to be taken into consideration (Geist, 2015). It has to be stressed that habitat degradation caused by fine sediment deposition can generally only be solved by catchment restoration. However, in-stream restoration is able to support and accelerate the recovery process (Mueller et al., 2013; Pulg et al., 2013; Denic and Geist, 2015; Hauer, 2015).

THE POST-RESTORATION PERIOD

Monitoring of restoration effects should start directly after implementation of restoration measures. Just like in restoration itself, site-specific monitoring concepts need to be designed to maximize the cost-benefit ratio between sampling efforts and monitoring results. In our example, a stratified randomized design with a decreasing frequency of sampling dates in time is planned. The stratified randomized design was chosen as restoration is carried out mainly in well-defined river sections and habitats, for which restoration success needs to be assessed. By this design, sampling is restricted to the river sections of interest, whereas distribution of sampling points inside these sections is random. A decreasing frequency of sampling dates is selected based on the assumption that the most pronounced effects of restoration on habitats are expected in the initial phases, conditions then becoming more stable with time. In addition to the scientific monitoring of stream restoration, another monitoring concept for public relations activities is being set up with support from sociology experts. This illustrates the complexity of conservation projects often necessitating collaboration of experts from different fields.

Another critical point is the sharing of knowledge and experiences among conservation working groups. There is a clear tendency to focus on publication of successful results and neglect the report of failures (Geist, 2015). However, reporting failures would prevent the repetition of mistakes and help to save money and time, which are the two main resource limitations in nature conservation.

PUBLIC RELATIONS

A central aspect of successful restoration projects is public relations work, as many measures, particularly in river restoration, can be carried out only with the support of local landowners and stakeholders. Hence, public relations work has to be carried out continuously in all three project periods. The information and participation of stakeholders already in the planning process of projects can strongly increase acceptance of measures. In case of ArKoNaVera, this resulted in the signing of supporting agreements by 37 institutions including municipalities, agricultural, fisheries and nature conservation organizations.

ACKNOWLEDGEMENTS

The project ArKoNaVera is funded by the German Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety, the German Federal Agency for Nature Conservation, the German Federal Ministry of Education and Research and the Bayerische Naturschutzfonds.

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