FRESHWATER MUSSEL RECOVERY STRATEGY FOR THE DELAWARE ESTUARY AND RIVER BASIN

PARTNERSHIP FOR THE DELAWARE ESTUARY INC.

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I. Introduction

Freshwater mussels are the most imperiled animals in the United States, and locally within the Delaware River Basin. The 2012 State of the Estuary Report (PDE 2012a, 2012b) describes the declining species richness and population range for the dozen native species within the Delaware Estuary and river basin (Fig. 1). Over the past 20 years, the conservation and restoration of rare mussel species has become a national priority. In recent years, this effort has broadened to include species that are classified as more common but which are declining in range and abundance.

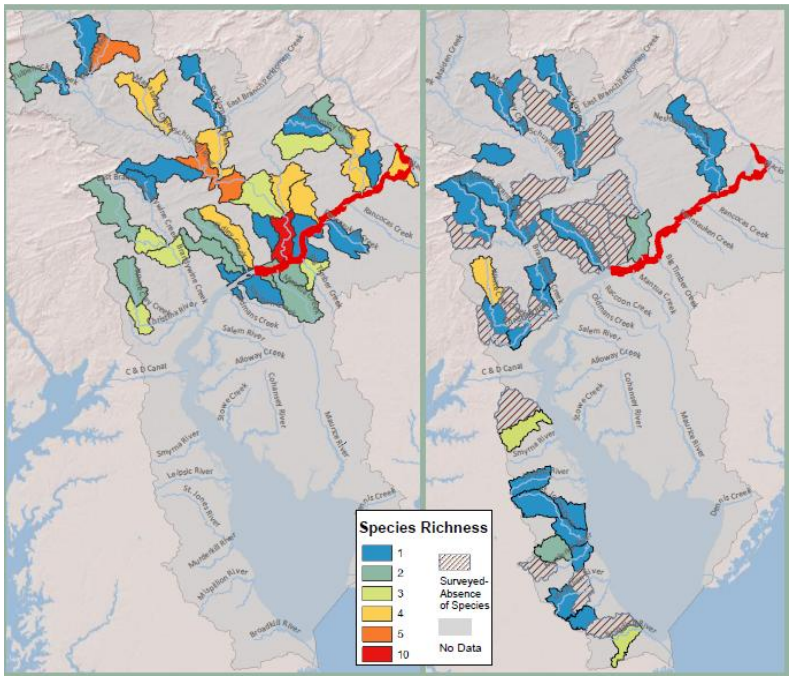

Figure 1. *Freshwater mussel species richness per watershed unit based on survey data from 1919 (left) and since 1996 (right) (PDE, 2012b).*

There are diverse reasons for this increasing interest in mussel conservation and restoration. State heritage programs and federal agencies (USFWS, USGS) have been primarily focused on biodiversity preservation and the protection of listed species. Recent interest at the federal (EPA), state (DEP) and local (townships, water companies) levels has centered mainly on the water and habitat benefits that

are furnished by healthy mussel beds in streams, rivers and lakes. Like marine species which have long been considered as sentinel bioindicators of aquatic health, healthy communities of freshwater mussels signify healthy streams and rivers.

As a National Estuary Program, the Partnership for the Delaware Estuary (PDE) is expected to establish measureable goals for sustaining and improving water and habitat conditions, thereby working to implement our Comprehensive Conservation Management Plan (CCMP). We recently elevated healthy freshwater mussel populations as one of a limited subset of "driver" goals which facilitate ecosystem-based restoration in the Delaware River Basin. This goal is based on the observation that mussels are very long-lived (up to 100 years) and sensitive to a variety of suboptimal conditions, ranging from water quality, water quantity, riparian cover, and fish passage. Hence, to achieve multiple goals for water and habitat conditions in any given water body, a simplified focus on achieving a healthy assemblage of native freshwater mussel species living in abundance will drive positive decision-making in support of broader CCMP actions and needs. Furthermore, since each adult mussel filters gallons of water every day, the fact that many areas once held abundant mussels but no longer is thought to contribute to degraded water quality. In those areas, mussel restoration will promote positive feedbacks to ecosystem health in the form of cleaner water, and possibly also reduced erosion and increased habitat complexity. Although we have adopted this goal to restore mussels as one key driver of ecosystem-based restoration and decision-making, importantly, we must continue to promote traditional restoration aimed at improving water and habitat quality to achieve this goal.

Although many current populations appear to be extremely depressed and constricted relative to historic levels, many scientists and managers believe that this represents an opportunity to rebuild mussel populations. Many streams and rivers that were once too polluted to support mussels have since been remediated to the point where mussel populations could again be sustained. However, fish passage blockages and other impediments stand in the way of mussels being able to naturally re-disperse and colonize the habitats. In other areas, there is interest in facilitating the pace of recolonization by directly augmenting natural populations since natural dispersal can be slow and unpredictable.

In scientific studies by us and others, mussel species richness (including rare species) has been found to be positively correlated with overall mussel population abundance (of common and rare species). This means that mussel restoration that builds populations of common species should also promote conditions that support threatened and endangered mussel species (i.e., there is no evidence of competition). Hence, conservation and restoration efforts that are aimed at both common and rare mussel species provide tools to strengthen the future resilience of aquatic ecosystems, protect drinking water supplies, and promote imperiled species. Additional information on the life history, status, and ecological importance of native freshwater mussels is available from PDE upon request.

II. Freshwater Mussel Recovery Program (FMRP)

In 2007, PDE launched the FMRP which seeks to conserve and restore native freshwater mussels across the Delaware Estuary and river basin primarily because of the link between healthy and robust shellfish populations and improved water quality. The FMRP is part of a broader, watershed-wide shellfish restoration strategy that includes marine mussels and oysters. The FMRP promotes multiple Action Items within the Comprehensive Conservation Management Plan for the Delaware Estuary Program (DELEP 1996; e.g. Actions W-2, W-12, H-1, H-10, E-6), which PDE and others strive to implement. The

FMRP is also directly supportive of the National Strategy being developed for freshwater mussel conservation and restoration.

The FMRP consist of the following **9 activities**:

1. **Surveys**. Despite their importance, freshwater mussels are not routinely monitored as part of state or federal assessments, and survey data have not been collected or obtained for many areas of the Delaware Estuary (Fig. 1). Yet, it is critical to establish baseline conditions for conservation and restoration. PDE staff and partners have been working to fill vital data gaps on mussel status and trends to: a) estimate current ecosystem services being provided by mussels for water quality models, b) identify areas that still have mussels and promote their conservation, c) identify areas that once held mussels and no longer do and promote restoration (where historical data exist), d) identify healthy populations that might be used to sustain mussel restoration and outreach efforts, and e) provide supportive data to states to augment updates to the conservation status of native species.

2. **Assessments**. Similar to marine species that have been used in an International Mussel Watch program for more than 50 years, freshwater mussels are exceptional bioindicators of water quality and aquatic system health. Their sessile nature and high filtration rates provide an opportunity to test and contrast the suitability of candidate restoration sites using caging or tagging protocols developed by PDE scientists (details available upon request). Funding and resources for mussel restoration are precious, and it is therefore imperative that restoration sites be strategically selected based on preliminary assessment using these protocols to maximize chances for success. Opportunities also exist for compound- or site-specific testing of ambient water quality or toxicity testing.

3. **Conservation**. With few exceptions , most native mussel populations in the Delaware River Basin appear to be in decline based on either species ranges or population abundance (although their status in most areas of NJ is reportedly more secure than in DE or PA). Mussel declines occur for a variety of reasons, including degraded or altered habitat, water quality, riparian cover, suitable fish hosts, stormwater, dams, dredging, or water flows. The FMRP operates under the premise that "every mussel is precious," and it is vitally important that vestigial mussel populations be identified and protected, especially in cases where natural reproduction appears to still be occurring or when federal or state-listed imperiled species are present. To protect mussel beds containing listed species, managers typically use species-habitat maps to make protective decisions. However, designation of Critical Habitat for protection of common species that furnish important ecosystem services is a new concept that is not yet routinely considered in conservation management.

4. **Restoration via Reintroduction**. Once water bodies are targeted for mussel restoration, the first step is usually to relocate gravid adults from genetically appropriate "nearest neighbor" populations (with necessary biosecurity protections). In situations where suitable host fish may not be present in recipient streams, another option is to relocate the actual fish hosts after they become infested with mussel larvae. If juvenile mussel "seed" are available from a hatchery (see #5), they can also be deployed into recipient streams. In 2011 and 2012, PDE scientists performed successful reintroductions of two mussel species into 3 southeast PA streams, and

subsequent monitoring using electronic tagging indicates that most animals survived record flooding and severe erosion (more details available upon request).

5. **Restoration via Propagation**. To achieve measureable uplift in water quality and other benefits sooner, mussel restoration can be broadened and expedited only through mass production of seed in hatcheries. Propagation is the only tactic that does not rely on or affect healthy existing populations. Here, broodstock mussels are collected from healthy natural beds (and later returned unharmed) at a time of year when females are actively brooding larvae. Suitable fish hosts are also collected, and mussels and fish hosts are then cultured together. The fish become "infested" with larvae that attach to their gills for a period of several weeks (with no harm to the fish). After mussel larvae transform (metamorphose), they drop off the fish and begin their life as juvenile mussels. At this point, mussel seed can be quickly reared to a suitable size for outplanting using new rapid culture methods in grow-out ponds. There have been many recent technical advances in the propagation of Atlantic Slope mussel fauna, and PDE has worked with diverse partners to resolve remaining propagation R&D needs. To be successful, a mussel hatchery will need committed support for a 4-5 year start-up period until production yields mussel seed of sufficient sizes for outplanting.

6. **Restoration via Habitat**. The habitat requirements of freshwater mussels vary by species; however, some universal needs are bottom stability, suitable flow, and a lack of toxic chemicals. Streams and rivers that are subject to flashy flows, high bed transport, dredging, insufficient flow, and certain contaminants will be unable to support healthy mussel assemblages. This presents an opportunity to expand the carrying capacity for native mussels by enhancing habitat and water quality conditions. For example, PDE is working to design living shorelines that include suitable substrates for mussels within a coastal "habitat mosaic." Projects that stabilize stream banks, reduce bed transport, remove dams, restore riparian cover, and restore submerged vegetation can also benefit mussels (with proper protections for any extant mussels). Since mussels can also be killed or stressed by certain contaminants (copper, aluminum, ammonium), measures to detoxify water quality or improve bottom chemistry are also included here. Habitat Suitability Indices and other metrics can help guide habitat-associated restoration (and mitigation).

7. **Research & Monitoring**. Data and information gaps can impede mussel recovery efforts and thwart our ability to link restoration to measureable outcomes and goals of managers. A better understanding is needed for the life history, physiological ecology, and carrying capacity for our local mussel species. Although it is important to examine historical context where data are available, increasingly, management paradigms are becoming more forward-focused due to climate and landscape change. To identify future niches that can support sustainable mussel assemblages and their ecosystem services, we need to develop predictive models of current and future carrying capacity for species that are likely to be sustainable. Life history information on suitable fish hosts is needed to support mussel reproduction (different mussel species depend on specific fish). Physiological data are needed to model beneficial water quality outcomes (for calculation of returns on investments). Restoration via habitat would be promoted with a better understanding of species-specific substrate and water quality needs, nutritional demands, and mutually beneficial relationships between mussels and other biota such as submerged aquatic vegetation and macroinvertebrates. Monitoring of previous restoration activities will be required to assess outcomes and facilitate adaptive management of the FMRP.

8. **Outreach**. PDE works to educate the public about the importance of freshwater mussels and their conservation and restoration through a variety of public presentations, outreach events, newsletter and website articles, and volunteer survey training workshops. In 2012, PDE produced a guidebook to the Freshwater Mussels of the Delaware Estuary. Observations of mussel occurrences can be furnished to PDE scientists via a new mussel data portal. To date, most of these efforts have been centered on southeast Pennsylvania and northern Delaware due to funding sources, but this component of the FMRP can be expanded geographically and through more diverse partnering and leveraging. Expanded outreach might also include "mussel gardening" of relocated animals or hatchery-produced juveniles.

9. **Coordination**. As a tri-state National Estuary Program, PDE has been working to launch and coordinate the FMRP among diverse sectors within the Delaware Estuary watershed. To date, core partners have included staff within the state environmental programs for Delaware, New Jersey and Pennsylvania, federal representatives at U.S. Fish and Wildlife Service, academic and non-profit research institutions (Academy of Natural Sciences of Drexel University, Cheyney University, Rutgers University), companies (e.g., Cardno-Entrix) and water supplies (e.g. Philadelphia Water Department, United Water). PDE intends to soon form a technical advisory workgroup affiliated with the Science and Technical Advisory Committee to coalesce and expand participation and provide technical peer review for the FMRP. Formation of this group would also facilitate interstate cooperation and link to national mollusk conservation priorities.

The FMRP abides by standard principles of conservation biology and environmental management. All activities are vetted *a priori* with state and federal partners and permit agencies. PDE maintains a reciprocal data sharing agreement with two of the partner states, and sensitive species data are maintained in confidence by all FMRP partners. Only genetically appropriate mussel stocks from the Delaware system are used in restoration activities. Protocols are being developed by a Mid-Atlantic mussel working group to ensure that suitable biosecurity protections (quarantine and disinfection methods) are in place and followed prior to any transfer of biotic material among ecologically disconnected locations.

III. Strategy Overview

To date, the FMRP has operated opportunistically relying on discrete grants, donations and voluntary contributions of partners and the public. Outcomes have included at least some progress in all nine activity areas in Section II, including important discoveries of rare and abundant mussels within one section of the Delaware River (Fig. 2), successful reintroduction to a few historic streams, advances in hatchery propagation at a partner university, and engaged participation and interest by the water utilities, managers and general public. However, attraction of more significant resources via national agency support, coordinated interstate support, or local mitigation funds is needed to materially advance the FMRP in a coordinated manner.

***Figure 2**. Recent discoveries and quantitative surveys indicate that a healthy and diverse assemblage of native freshwater mussels still resides within the freshwater tidal Delaware River, offering hope that many native species can be restored to areas where they have become extirpated.*

The purpose of this strategy document is to build awareness, support and broader participation for a proactive, coordinated Freshwater Mussel Recovery Program that leads to measureable beneficial outcomes for water quality, habitat conditions, and future resiliency in the face of changing watershed, demographic and climate conditions.

IV. Five Year Plan

The table below summarizes the optimal activities, partnering arrangements, estimated costs and outcomes associated with full implementation of the nine activity areas in the 5-Year Delaware Estuary Mussel Recovery Strategy. Estimated measures of past progress are also listed to provide a context for expected outcomes.

Although many activities are interrelated and synergistic, it is not imperative that all activities be implemented together and in this order. We recognize that funder and partner interests have and will steer the path for the FMRP. Due to past progress and support within southeast Pennsylvania, and more recently northern Delaware, we anticipate that next steps will advance more quickly in those areas. However, the goal of this 5-year plan is to have all nine activity areas (Section II) at least partially implemented in all three states by 2018 (expansion to NY is also possible via partners). This plan does not include the many additional leveraging opportunities and contributions by partners or tangential benefits in the form of student training and public awareness. By working together and strategically using all of the resources at our disposal to address the needs illustrated in this table, we believe that

PDE and its NEP partners can create a sustainable program for native mussel conservation and restoration in the Delaware Estuary.

The total projected costs for full implementation of the 5-year Strategy are shown at the bottom of Table 1, $4,525,000. Potential sources of funding include major donor support, the business sector, non-profit sector, three states, and the federal government. For more information about the FMRP or any activity area described in this document, please contact the individuals below.

V. Contacts

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VI. References

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Activity	Task	Partners	Past Progress	Future Needs	Approx. Cost	Outcomes
1. Surveys	Qualitative	academia, industry, non-profits, states	15% of area	5 HUC-12's per year per state	$25,000 / year / state	50% of area surveyed by Yr 5 (e.g. 2018)
	Quantitative		<5% of area	as possible in larger beds	$40,000 / year	4X more mussel sources identified by Yr 5
2. Assessments	Restoration Readiness Tests	academia, states, watershed groups	~5%	5-8 candidate sites compared per year	$20,000 / year	25% of candidate sites assessed, examples in 3 states, by Yr 5
	Water Assessment	industry, agencies, academia	<1%	as requested	scaled to emerging needs	demostrated utility for toxicity testing and
3. Conservation	Habitat-Species Mapping	non-profits, academia, state & fed agencies	0%	GIS tools to predict suitable habitat from survey data (#1), ground-truthing, and other physiological boundary conditions (#7)	$20,000 per year	25% of critical habitat mapped by Yr 5
	Critical Habitat identification	state and fed agencies, non-profits		Coordination among agencies to implement protections	$3,000 per year	15% of critical habitat protected by Yr 5
4. Restoration via Reintroduction	Adult Transplants	non-profits, academia	<5%	5 candidate sites per year	$25,000 per year	15% of suitable sites receiving at least 1 mussel species by Yr 5
	Seed Stocking	non-profits, academia, industry	0%	3 candidate sites per year beginning year 4	$20,000 in Yr 4 and Yr 5	5% of suitable sites receiving seed by Yr 5
5. Restoration via Propagation	Restoration Aquaculture Center	non-profits, academia, industry, agencies	0%	5-year start-up of co-op mussel hatchery (e.g. at FWWIC)	$700K in Yr 1, $480K per Yrs 2-5)	Seed supply source created for upper mid-Atlantic region by Yr 4
	Satellite Hatcheries	academia, non-profits	25%	Fish infestation support, pond grow-out support (1/state)	$75,000 / year in Yrs 3-5	Grow-out facilities in each state by Yr 4, outplanting by Yr 5
6. Restoration via Habitat	Living Shorelines	non-profits, academia, states, industry	0%	scoping & permitting in Yrs 1 3, installation Yrs 3-4, monitoring Yr 5	$20,000 per year for mussel portion	at least 2 LS sites containing sustained mussel beds
	Habitat BMP's	non-profits, states, watershed groups	0%	interpret data from #3, 7 for managers	$5,000 per year	guidelines for land and water managers to promote mussels
7. Research & Monitoring	Life History	academia, non-profits	5%	mussel-fish and mussel-SAV studies	$20,000 per year	Assessment of of past outcomes, estimation of future attainable water quality outcomes, and geographical guidance to maximize future restoration success; training of graduate students (future scientists and managers)
	Physiology & Carrying Capacity	academia, non-profits	10%	filtration rates, biogeochemical services, popn uplift potential	$30,000 per year	
	Site Monitoring	academia, non-profits, watershed groups	<5%	performance evaluation and adaptive management of sites	$15,000 per year	
8. Outreach	Info Products	academia, non-profits	25%	enhance website, data portal, revise mussel handbook, target more areas	$5,000 per year	readily available, informative materials and broad awareness for the importance of mussels and their conservation & restoration
	Workshops	academia, non-profits, watershed groups	10%	3 workshops per year in new areas	$15,000 per year	
	Mussel Gardening	non-profits, watershed groups	0%	develop and implement tactics for gardening, launch a pilot per state	$15,000 in Yr 4, $25,000 in Yr 5	direct engagement of the public in mussel restoration and awareness of water quality needs
9. Coordination	Technical Advisory Group	academia, states, fed agencies, non-profits	0%	establish peer review group of scientists and managers for DRB	$3,000 per year	knowledgeable participation, linkages and oversight of FMRP
	Info Sharing	FMRP PI reps	5%	connect FMRP to National Strategy, share outcomes	$3,000 per year	FMRP linked to and supportive of national priorities
Total (5 Years)					**$4,525,000**	
Total (per year &					**$301,666.67**	