REVIEW
of

The Asian clam (*Corbicula fluminea*) and its relationship to the balanced indigenous population (“BIP”) in Hooksett Pool, Merrimack River, New Hampshire

Prepared for
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Credentials of the Reviewer:

Dr. Robert F. McMahon received a B.A. degree in Zoology from Cornell University in 1966 and a Ph.D. degree in Zoology from Syracuse University in 1972 specializing in aquatic biology, physiological ecology with an emphasis on aquatic molluscs. He joined the faculty of the Department of Biology at The University of Texas at Arlington in 1972 where he retired as Professor of Biology and Dean of the Honors College in February 2009. Dr. McMahon was a Fulbright Research Fellow at Trinity College, Dublin, Ireland, during 1979-1980. During his tenure at UT Arlington he also served as Director of the Center for Biological Macrofouling Research, Director of the Graduate Program in Environmental and Earth Science, and Associate Dean of the College of Science. After retiring, he was awarded the title of Professor Emeritus and continues to conduct research on the biology, ecology, physiology and management/control of aquatic invasive molluscs, particularly Asian clams (*Corbicula fluminea*), zebra and quagga mussels (*Dreissena polymorpha*, *Dreissena rostriformis bugensis*), and island apple snails (*Pomacea maculata*). He has published over 135 research papers and treatise chapters on the biology, ecology, and physiology of freshwater and marine molluscs. Of these, 31 publications have dealt with aspects of the biology and control of Asian clams and 33 with that of dreissenid mussels. He is considered a world expert on these two aquatic invasive species. He has also written over 40 technical reports on the management and control of invasive Asian clams, dreissenid mussels and apple snails. His research has been funded by the US Fish and Wildlife Service, US Army Corps of Engineers Water Ways Experiment Station, US National Science Foundation, Texas Parks and Wildlife Department, and electric power and chemical industries. He has served on the Western Regional Panel on Aquatic Nuisance Species and the Federal Invasive Species Advisory Committee. He presently serves on the Gulf and Southern States Panel on Aquatic Nuisance Species and the Texas Invasive Plant and Pest Council. He is a member of the editorial boards for two international biological research journals and serves as a reviewer for many others. Dr. McMahon has been and continues to be active as an independent consultant on the biology and control of invasive and medically important aquatic molluscs. He was presented with the 2014 National Lifetime Achievement Award for his work on aquatic invasive species by the National Invasive Species Council (NISC) on February 25, 2015 at a ceremony held during National Invasive Species Week in Washington, DC.

Review of AST Environment Report

I have carefully reviewed the AST Environmental report entitled "The Asian clam (*Corbicula fluminea*) and its relationship to the balanced indigenous population ("BIP") in Hooksett Pool, Merrimack River, New Hampshire." The report analyzes and reviews the extensive data set collected on Asian clams and benthic invertebrates in Hooksett Pool on the Merrimack River, New Hampshire. It centers on the impacts (if any) of the invasive Asian clam population on the BIP of benthic macroinvertebrates and native bivalves in Hooksett Pool and the impact, if any, of the thermal effluent discharge into the pool from the Public Service Company of New Hampshire coal fired Merrimack Station on sustaining the pool's Asian clam population.

Using data collected by Normandeau Associates, Inc. and from other sources [i.e., the USEPA and the New Hampshire Department of Environmental Services (NHDES)] on the population of

Asian clams, other bivalves (*Elliptio* sp. and Sphaeriidae) and benthic macroinvertebrates in Hooksett Pool and of Asian clam presence in other areas of the Merrimack River and from other populations in New Hampshire not receiving thermal effluents, Dr. Terry Richardson of AST Environmental evaluates whether the area of Hooksett Pool receiving thermal effluents from the Merrimack Station acts as winter refuge for the resident Asian clam population and if that clam population is negatively impacting the BIP of the Pool's native bivalve and benthic macroinvertebrate communities.

The Asian Clam Population in Hooksett Pool

The AST Environmental report indicates that USEPA and NHDES data revealed no significant differences in the densities among New Hampshire aquatic habitats harboring Asian clam populations including Hooksett Pool and Amoskeag Pool receiving thermal effluents from the Merrimack Station and Cobbetts Pond and Long Pond not receiving thermal effluents. In addition, Table 5 of the report cites 11 locations in New Hampshire water bodies harboring Asian clam populations but not receiving thermal effluents including those in Hooksett Pool 2000 feet and one mile above the Merrimack Station thermal effluent outlet. These data strongly suggest that thermal effluents are not required to support sustainably reproducing Asian clam populations in New Hampshire water bodies. They also suggest that Asian clams do not require a thermal refuge to invade and thrive in New Hampshire water bodies as corroborated by a report that Asian clam populations have been found at 24 cold winter water sites in the Arkansas, Colorado, Platte, and San Juan River Basins of Colorado not receiving thermal effluents (Cordeiro et al. 2007). The Colorado water bodies and rivers supporting Asian clam infestations were at high altitudes (i.e., 1,200 to 3,200 m) where they were exposed to extremely low winter temperatures. Asian clams have also become established in Lake George, NY, which ices over every winter (Young and Wick 2017). A sustainably reproducing Asian clam population occurs in the Clinton River, Michigan, where ambient water temperatures range from 0-2°C for most of the winter (Janech and Hunter 1995). Further, an Asian clam population established in a section of the lower Connecticut River in 1990 impacted by thermal effluent discharge from the Connecticut Yankee Nuclear Power Station continued to thrive at similar densities after the Power Station was closed in 1997 and ceased to release thermal effluents (Morgan et al. 2004).

Asian clams were first discovered in Europe in 1980 in the Bass Dordogone, France, and Tage Estuary, Portugal (Mouthon 1981). They have since spread throughout Europe extending west into Germany, Poland, Ukraine and Romania (DAISIE 2017) where they have invaded freshwater habitats with very low winter ambient temperatures (Müller and Baur 2011). In a laboratory study (Müller and Baur 2011), small and large winter-conditioned specimens of Asian clam were exposed to constant water temperatures of 0° and 2°C for a period of nine weeks while recording their mortality weekly. Clams had a high level of survival (>80%) during the first four weeks of exposure to ether 0° or 2°C after which mortality rapidly increased with further exposure time. However, some larger individuals (17.5%) survived the full 9 weeks of exposure. Overall, large individuals were more cold tolerant than small individuals (Müller and Baur 2011). Since water temperatures in northern temperate lotic systems do not remain at or below 2°C throughout the winter, including the Merrimack River, NH, this result explains the survival of Asian clam populations in areas of that river not receiving thermal effluents as noted in the AST Environmental report.

Taken as a whole, these published studies and the data provided in the AST Environmental report strongly suggest that Asian clams are capable of sustaining populations under very cold conditions in the Northeastern United States, belying previous laboratory studies indicating that they could not survive continuous exposures to ambient water temperatures ≤ 2.0°C (Mattice and Dye 1976). However, the Mattice and Dye (1976) study was conducted on Asian clams sampled from the Clinch River, Tennessee, where acclimatization to a relatively warm-water environment may have resulted in an elevated lower thermal limit. In fact, the AST Environmental report showed that Computation Fluid Dynamic thermal modelling of winter ambient water temperatures in Hooksett Pool indicated that benthic water temperatures ~290 m below the outfall of the Merrimack Station thermal effluent did not elevate ambient benthic water temperatures above the previously assumed Asian clam lower thermal limit of 2°C (Mattice and Dye 1976) from December through March. Indeed, winter benthic water temperatures at this site were similar to those above the station's thermal outlet where Asian clams also survived overwinter. These data and reports of thriving Asian clam populations in New Hampshire, Connecticut, Colorado and northern Europe (as described above) strongly suggest that even if the release of thermal effluents from the Merrimack Station into Hooksett Pool ceased, its Asian clam population would continue to exist because it appears to be tolerating ambient winter water temperatures below 2°C as are Asian clam populations upstream and downstream of the station's localized thermal effluent plume. Further, the Asian clam's extremely high reproductive and growth rates (McMahon 1999) would allow replenishment of any winter clam mortality during summer months by the indigenous population as well as by settlement of juvenile clams hydrologically transported (McMahon 1999) into Hooksett pool from populations upstream of the Merrimack Station. Moreover, if cooling tower basins are used to replace the existing once-though cooling system at Merrimack Station, the winter thermal refugia associated with the warm water in such cooling towers and blowdown discharge of warm water from cooling tower basins into Hooksett Pool would likely support Asian clam reproductive efforts (Post et al. 2000).

Impact of Asian Clams on the Balanced Indigenous Population (BIP) of Native Bivalves and Benthic Macroinvertebrates in Hooksett Pool

In the opinion of this reviewer, Dr. Richardson provides strong empirical evidence from extensive field sampling that the Asian clam population is not causing appreciable harm to the balanced indigenous populations (BIP) of either native bivalves or benthic macroinvertebrate communities in Hooksett Pool.

Native Bivalves

In order to assess the possible impacts of Asian clams on native unionid mussels (*Elliptio* sp.), AST and Normandeau divers (SCUBA) conducted surveys along transect lines across the Merrimack River at four stations above the Merrimack Station thermal effluent discharge (i.e., two in upstream Garvins Pool and two in upstream Hooksett Pool) and six stations downstream from the station's thermal discharge (five in Hooksett Pool and one in the downstream

Amoskeag Pool below Hooksett Pool in 2014 and 2016). Divers visually and tactilely searched for unionid mussels on a 1 m wide path on either side of the transect lines and qualitatively assessed mussel abundance. In addition, to transect line surveys, divers excavated five, 0.25 m^2 quadrate sediment samples, to a depth of 15 cm at three quarter distances along the transect lines (one ¼ , one ½ and one ¾ the distance from shore to shore). Of each set of five samples, three were randomly chosen to be sieved and the shell length of collected unionids and Asian clams were measured and recorded. Additionally, two or three ponar benthic grab samples were taken at each of the three quarter distances along the transect lines. Each of these samples was sieved and sorted for all macroinvertebrates including Asian clams and unionids. The data from the ponar samples were then utilized to compute macroinvertebrate abundances, taxa richness, Shannon Diversity, EPT taxa richness, and the Hilsenhoff Biotic Index.

The dominant unionid mussel in the transect samples was *Elliptio complanata*. Its densities were determined for transect N10 above the Merrimack Station without Asian clams and compared to those for transects S0, S4 and S24 below the thermal discharge in Hooksett Pool with Asian clams in 2014 and 2016. While there was a significant ($p = 0.014$) difference in *E. complanata* density between the two years, no significant ($p <0.05$) differences in mussel density occurred among sites. Nor were there significant ($p = 0.65$) differences in the size frequency distributions of samples of specimens of *E. complanata* between site N10 without Asian clams and the combined data for sites S0, S4, and S24 with Asian clam populations. The fact that there were no significant differences in the densities or size distributions for populations of *E. complanata* between a site without Asian clams above Hooksett Pool and three sites with Asian clams within Hooksett Pool suggests that Asian clams in Hooksett Pool were not negatively impacting the densities, growth rates or survivorship of its unionid population. Essentially similar results were recorded for sphaeriid clams in Hooksett Pool (reported as *Pisidium* sp.) whose densities changed significantly ($p = 0.003$) across sampling years but not among sampling sites with and without Asian clams ($p = 0.416$).

Based on lack of difference between the densities and size structures of populations of the native unionid mussel, *E. complanata*, upstream of and within the area of Hooksett Pool colonized by Asian clams, the AST Environmental report suggested that the presence of Asian clams in Hooksett Pool was not negatively impacting the resident unionid and sphaeriid bivalve populations. As alluded to in the AST Environmental report, there have been a number of published studies that have suggested that Asian clams can outcompete native unionid mussels for phytoplankton and benthic food resources and space in sediments resulting in reductions in unionid density or complete extirpation after Asian clam invasion (reviewed by Strayer 1999, Vaughn and Hakenkamp 2001, and Sousa et al. 2008). Unfortunately, most of these postulated impacts of Asian clams on unionids have not been supported by empirical studies. Indeed, as indicated in the AST Environmental report and my own extensive literature search for this review, there appears to be scant published empirical evidence for negative impacts of Asian clams on native unionids and other freshwater bivalves. Thus, the main empirical reports of negative impacts of Asian clams on native unionid mussels have involved reported declines in unionid densities after Asian clam invasion of their habitats (Gardener et al. 1976, Sousa et al. 2005, Cordeiro et al. 2007). However, these reports are observational and did not ascertain the actual interaction with Asian clams that caused the observed native mussel density declines. Fuller and Richardson (1977) described Asian clams potentially dislodging native unionids from the substratum in the Savannah River (Georgia and South Carolina) but did not observe actual unionid dislodgement or unionid mortality resulting from it.

In contrast, most empirical studies have found no negative impacts of Asian clams on native unionid mussel or sphaeriid populations supporting the observation of no impact in the AST Environmental report. For example, Asian clams were first documented in the Connecticut River near the Connecticut Yankee Power Station in 1990. When sampled along with native unionid mussels and sphaeriid clams from 1991-2000, no significant trends in unionid, sphaeriid or Asian clam abundance occurred across the entire sampling period including when the plant was operational and generating a thermal effluent during 1991-1996 and after it was shut down from 1997-2000 suggesting that Asian clam invasion had not negatively impacted either the unionid or sphaeriid communities (Morgan et al. 2004). In a study of 30 stream reaches in eight rivers in the Ouachita Highlands of central and western Arkansas and eastern Oklahoma, Vaughn and Spooner (2006) found that, when measured at the entire site scale rather than as separate quadrates, Asian clam densities were not significantly correlated with mean unionid mussel densities ($p = 0.95$) or biomass ($p = 0.76$) indicative of no Asian clam impact. Similarly, Leff et al. (1990) in a study of bivalve distribution and abundance in 79 perpendicular transects separated by 100 m along a stretch of a backwater stream tributary to the Savannah River, found no significant correlation between the densities of Asian clams and the unionid, *Elliptio complanata*. Instead, their densities across sites appeared to vary independently from each other. These three empirical studies have all indicated that Asian clam infestations do not impact either sphaeriid or unionid density or biomass (BIP) including that of the unionid species, *E. complanata* that was also found not to be impacted by the presence of Asian clams in Hooksett Pool by the AST Environmental study.

Benthic Macroinvertebrates

The data from the AST Environmental study indicated that, when sampled in 2014 and 2016, total benthic macroinvertebrate abundances not including Asian clams varied significantly ($p <0.05$) among the 10 sampling sites (i.e., four sites without Asian clams and six sites with Asian clams upstream and downstream of the Merrimack Station thermal discharge into Hooksett Pool, respectively). However, there was no clear pattern of difference between the four sites with and six sites without Asian clams. Nor were they significantly ($p >0.05$) different at two sites within the Merrimack Station's thermal plume in Hooksett Pool in years prior to (1972, 1973) and after (2011, 2014, 2016) Asian clam invasion. Similarly, there was no difference in benthic macroinvertebrate taxa richness at all ten sampling stations in 2014 while it was statistically equivalent or greater at Asian clam sites compared to those without clams in 2016. Further, benthic macroinvertebrate taxa richness values (not including Asian clams) at the two sites (S4 and S17) with the highest abundance of Asian clams were not significantly different among years (1972, 1973) prior to and after (2011, 2014 and 2017) Asian clam invasion. Like taxa richness data, Shannon Weaver Diversity Indices (not including Asian clams) were not significantly ($p >0.05$) different among all 10 sampling stations in 2016 and, while significant ($p <0.05$) differences among sites occurred in 2014, there was no observable trend in the differences between sites with and without Asian clams. As with taxa richness, Shannon Diversity Indices for benthic macroinvertebrate taxa richness values (not including Asian clams) at the two sites (S4 and S17) with the highest abundance of Asian clams were not significantly different among years prior to (1972, 1973) and after Asian clam invasion (2011, 2014 and 2017). Similarly, Hilsenhoff Biotic Indices (HBI) for benthic macroinvertebrates were not significantly (p .0.05) different among all ten stations in 2016 and showed no consistent trend in differences between sites with and without Asian clams in 2014. When compared across samples taken at two sites (S4 and S17), pre- (1972 and 1973) and post- (2011, 2014 and 2016) Asian clam invasion, HBI was insignificantly ($p > 0.05$) different across years or significantly ($p < 0.05$) lower in post-invasion years indicating either no change in or improved biotic integrity at the sampled sites after Asian clam invasion. Similarly, EPT Taxa Richness values (not including Asian clams) were not significantly ($p > 0.05$) different across all 10 sampling stations in 2014 and were either not different or significantly ($p < 0.05$) higher at Asian clam sites in 2016. Benthic macroinvertebrate EPA Taxa Richness values (not including Asian clams) at the two sites (S4 and S17) with the highest abundance of Asian clams were not significantly ($p > 0.05$) different among years prior to (1972, 1973) and after (2011, 2014 and 2017) Asian clam invasion at site S17 while at site S4, they were equivalent to or significantly ($p < 0.05$) greater than occurred prior to Asian clam invasion.

All of the above described results consistently suggest that benthic macroinvertebrate abundance and diversity in areas of Hooksett Pool with Asian clams have either remained unchanged or have significantly increased resulting in no change to or an increase in biotic integrity as measured by the Hilsenhoff Biotic Index. Thus, the data support AST Environmental's conclusions that Asian clams are not negatively impacting the BIP of the Hooksett Pool benthic macroinvertebrate community.

As with early untested speculation that Asian clam infestations would negatively impact native bivalve populations, it was also hypothesized that Asian clams could negatively impact benthic macroinvertebrate communities by displacing or reducing habitat for other macroinvertebrate species, their burrowing causing sediment turnover and changing abiotic conditions in pore water and the overlying water column, increasing benthic habitat heterogeneity through shell accumulation providing hard substratum, clarification of the water column allowing increased coverage by rooted aquatic macrophytes, reducing macroinvertebrate settlement rates, shells increasing shelter and reducing food resources by the clam's filter feeding on seston and pedal feeding on detritus (Cohn et al. 1984, Phelps 1994, Hakenkamp and Palmer 1999, Strayer 1999, Vaughn and Hakenkamp 2001, Werner and Rothhaupt 2007, Sousa et al. 2008, Ilarri and Sousa 2011, Bullard and Hershey 2013, Majdi and Gilbert 2014).

In spite of the many hypotheses proposed for potential negative impacts of Asian clams on benthic macroinvertebrates, there have only been a limited number of empirical studies conducted that actually test the validity of these hypotheses (see Ilarri and Sousa 2011, Karatayev et al. 2003 for reviews). Interestingly, the reviewer's literature search indicated that empirical studies have overwhelmingly shown that Asian clams either have no impact or a positive impact on macroinvertebrate communities. For instance enclosures submerged in Lake Constance (Germany, Switzerland, Austria) containing sand only, sand with half shells of *C. fluminea* at 2000 shells/m^2 or sand with 1000 living Asian clams/m^2 for 2 months showed no significant differences in overall benthic macroinvertebrate density, suggesting that empty clam shells or living Asian clams had no impact on the development of benthic macroinvertebrate communities. Of nine benthic macroinvertebrate taxa individually examined in this study, only those of the Hirudinea (leeches) and C*aenis* sp. (Mayfly) differed among enclosures with both groups having significantly increased densities in enclosures with clam shells (Werner and Rothhaupt 2007). Similarly, when the densities of Asian clams and benthic macroinvertebrates were sampled along six transects in Lake Nacogdoches, Texas, there were no significant ($p > 0.05$) correlations between the density of Asian clams and those of 38 sampled benthic macroinvertebrate taxa (Karatayev et al. 2003) again suggesting that the clams were not negatively impacting benthic macroinvertebrate communities. Linares (et al. 2017) found that the presence of the invasive bivalves, *Corbicula fluminea* and *Limnoperna fortunei*, enhanced the complexity and diversity of benthic macroinvertebrates in four neotropical Brazilian reservoirs. Pereira et al. (2017) recorded the densities of Asian clams and benthic macroinvertebrates at 40 sites in a series of interconnected drainage ditches in the Vouga River Basin of the central region of Portugal. The results of their research indicated that Asian clams had "no impact on benthic communities" with differences in site environmental conditions accounting for 65.5% of the variation in the benthic macroinvertebrates and Asian clams only an insignificant 2.9%.

In the freshwater Minho Estuary, Portugal and Spain, transect sampling showed that Shannon and Pielou diversity indices for benthic macroinvertebrates were highly positively correlated with Asian clam density (Sampaio and Rodil 2014) suggesting that Asian clam presence increased the diversity and stability of the benthic macroinvertebrate community. The authors suggested that accumulation of Asian clam shells on an otherwise sand/silt substratum increased habitat heterogeneity favoring increased species richness. In another study of the impacts of Asian clams on the macroinvertebrate community in the Minho Estuary, Novalis et al. (2015) set out a series of 400 cm^2 enclosures with open tops and 10 mm mesh screening on their sides on a predominately fine/very fine sand substratum. The enclosures were then seeded with either nothing (controls), smooth rocks of nearly the same size and shape as Asian clams, dead Asian clam shells glued shut, live Asian clams, and dead, open Asian clam shells all at a density of $1200/m^2$. After two months, the enclosures were sampled for the density, biomass, species richness and diversity of benthic macroinvertebrates. Non-metric multidimensional scaling ordination analyses indicated no difference in the macroinvertebrate assemblages with the enclosures among the five different treatments. However, significantly higher macroinvertebrate density ($p = 0.01$), biomass ($p < 0.05$), and species richness ($p < 0.05$) occurred in enclosures with living and open clam shells. In contrast, no difference ($p = 0.13$) occurred in the Shannon-Wiener Diversity Index among the five treatments. The authors hypothesized that the presence of living Asian clams and dead open clam shells augmented macroinvertebrate density, biomass and species richness by production of feces and pseudofeces used as a food source by other benthic macroinvertebrates, empty shells increasing habitat complexity, thus providing shelter and hard substratum for attachment and periphyton growth, and reworking of sediments by clam burrowing and movement (Novalis et al. 2015).

Indeed, the only documented negative impact of Asian clams on benthic communities was a reduction in benthic meiofunal bacteria and flagellates presumably as a result of Asian clams pedal feeding on detritus, but no impact on benthic meiofaunal protists or other meiofaunal taxa including nematodes, rotifers, copepods, oligochaetes, juvenile *Corbicula*, ostracods, cladocerans, mites and chironmids (Hakenkamp et al. 2001).

Thus, the available empirical studies all show that Asian clams either increase or do not impact benthic macroinvertebrate density, species richness or diversity. They increase habitat heterogeneity by deposition of hard shell substrata to soft sand/silt sediments, reworking sediments or transfering energy attained through their filter feeding on pelagic phytoplankton and bacterioplankton into benthic sediments with their feces and pseudofeces providing additional food resources to benthic macroinvertebrates. In contrast, my extensive literature search revealed no studies that showed the presence of Asian clams significantly negatively impacted benthic macroinvertebrate community species abundance, richness, or diversity. Thus, the available empirical studies support the outcome of the AST Environmental study showing that the Hooksett Pool macroinvertebrate community was not negatively impacted in areas occupied by Asian clams compared to sites without Asian clams or between years when Asian clams were not and were present in the pool.

Concluding Comments

Dr. Richardson's conclusions in the AST Environmental report that 1) elimination of the Merrimack Station's thermal effluent discharge will not eliminate Asian clams from Hooksett Pool, 2) the presence of Asian clams is not negatively impacting Hooksett Pool's native unionid and sphaeriid bivalve communities and 3) the presence of Asian clams is not negatively impacting Hooksett Pool's benthic macroinvertebrate community are strongly supported by the field sampling and thermal effluent temperature modeling data provided in the report and the preponderance of empirical studies of Asian clam cold tolerance and its interaction with native bivalve and benthic macroinvertebrate communities as detailed in the AST Environmental report and this review. Indeed, the reviewer's careful examination of available extant literature revealed that invasive Asian clam populations in North America, South America and Europe, when empirically studied, did not impact native bivalve communities and either had no impact on or enhanced the abundance, biomass, species richness and/or diversity of macroinvertebrate taxa. Their accumulated shells increase habitat heterogeneity, provide protection and hard surfaces for attachment and periphyton grazing for other benthic taxa. Their filter feeding transfers energy from pelagic phytoplankton and bacterioplankton to the benthic macroinvertebrate community in the form of their feces and pseudofeces as food resources and their burrowing and movements rework surface sediments. As such, negative impacts of Asian clams on aquatic communities as postulated in early reviews of its invasions in North and South America and Europe have not been supported by empirical studies.

It is also unlikely that elimination of the thermal effluent discharge from the Merrimack Station will eliminate the Asian clam population from Hooksett Pool because populations are sustainably surviving overwinter upstream and downstream of the plant's thermal plume, Further, Asian clams have been shown to be able to survive low winter water temperatures in North America and northern Europe and are likely to find warm water refuges in cooling tower basins (if they are used to replace the present once-through cooling system) and warm water blowdown from them into Hooksett Pool (Post et al. 2000). In addition, hydrological transport of juveniles spawned by clams in these winter thermal refuges and from upstream populations in the Merrimack River and overwintering clams in Hooksett Pool along with rapid juvenile growth rates after settlement appears likely to result in sustaining the Pool's clam population by compensating for any overwinter adult mortality (Morgan et al. 2004, Müller and Baur 2011). Indeed, further climate change induced warming of winter ambient water temperatures in northeastern US waterways, including the Merrimack River, could further support the Hooksett

Pool *C. fluminea* population even if all sources of thermal discharge were eliminated (Müller and Baur 2011, Verbrugge et al. 2012).

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