EXECUTIVE SUMMARY

THERMAL TOLERANCE, PHYSIOLOGIC CONDITION, AND POPULATION GENETICS OF DREISSENID MUSSELS (*DREISSENA POLYMORPHA* AND *D. ROSTRIFORMIS BUGENSIS*) RELATIVE TO THEIR INVASION OF WATERS IN THE WESTERN UNITED STATES

John T. Morse and Robert F. McMahon
The University of Texas at Arlington

Recent invasion of warm, often isolated, water bodies in the southwestern United States by *Dreissena polymorpha* and *D. rostriformis bugensis* has created a growing concern populations in these habitats could evolve thermally-tolerant lineages in both species resulting in the further southern, southwestern expansion of their North American range. An incipient chronic upper thermal tolerance limit of 27.2°C was determined for specimens of *D. rostriformis bugensis* collected in May 2007 from Lake Mead (NV/AZ). This result was similar to previous estimates for this species and suggested that *D. rostriformis bugensis* populations could thrive in Lake Mead at depths ≥12 m in which maximum ambient water temperatures remained below 27°C. The subsequent invasion of *D. rostriformis bugensis* populations into warm, shallow southern California reservoirs and the lower Colorado River where summer ambient water temperatures exceed its known incipient upper thermal limit appears to be the result of genetic selection in populations isolated in upstream drainages. Indeed, the recent development of dense adult populations of this species in the near-surface waters of Lake Mead (NV/AZ) may be a result of such thermal adaptation, increasing the potential for future dispersal of *D. rostriformis bugensis* into other southwestern United States water bodies from which this species was previously thought to be thermally

excluded, particularly as it was considered to have an incipient thermal tolerance limit ≈ 1-2°C lower than that of *D. polymorpha.*

Chronic thermal tolerance limits determined for individuals of *D. polymorpha* from Lake Oologah (OK) indicated that ambient summer lake water temperatures would induce extensive mortality events. Thus, the *D. polymorpha* population in Lake Oologah (OK) suffered two successive mortality events in the summers of 2006 and 2007 essentially extirpating this population. If the Lake Oologah population *D. polymorpha* has been extirpated, it would be the first recorded instance of a natural dreissenid population extirpation in North America. However, two possibilities exist for the reestablishment of a *D. polymorpha* population in Lake Oologah (OK). First, the population could be reinitiated by additional invasion events, and second, the few remaining, presumably more thermally tolerant individuals, could repopulate the lake resulting in a genetically-distinct, thermally-tolerant lineage of *D. polymorpha*.

This study revealed that a thermally-tolerant lineage of *D. polymorpha* may already exist in Winfield City Lake (KS). With an incipient upper lethal temperature of 30.7°C determined in this study, the Winfield City Lake *D. polymorpha* population is the most thermally-tolerant population of this species ever recorded in North America or Europe. The highest ambient summer water temperatures in Winfield City Lake (KS) were below the upper incipient thermal tolerance limit of 30.7°C recorded for specimens of *D. polymorpha* in that water body. While it is possible that this result was due to non-genetic acclimatization and phenotypic plasticity it is not supported in the published dreissenid literature. In contrast, this study, along with previously published data, presents strong evidence that it is very likely to be the result of thermal selection for a genetically-based, thermally-tolerant lineage. Development of a thermally tolerant lineage of *D. polymorpha* in Winfield City Lake and almost certainly in other Kansas and Oklahoma water bodies may have been the basis for the recent further southern expansion of this species into Lake Texoma (OK/TX) from they were presumed to be thermally restricted.

Specimens of *D. polymorpha* from Winfield City Lake (KS) were shown in this study to undergo a major reduction in body tissue mass at ambient water temperatures above 20–25°C which was most pronounced in larger individuals. This loss of body tissue mass at elevated ambient water temperatures suggested that individuals were in negative energy balance and could explain the progressively increasing extensive summer mortalities and possible extirpation of dreissenid mussels following extended thermal stress in the warmer waters of Lake Oologah (OK) in 2006 and 2007. Indeed, in early summer (29 June 2007) a standard individual of 25-mm shell length from Lake Oologah (OK) had only 35.4% of the dry tissue body mass of a similar-sized specimen from Winfield City Lake on 29 June 2008. Considering that Winfield City Lake (KS) mussels had achieved maximum tissue mass on 29 June and that 25-mm SL specimens had lost 49% of that mass by early August 2008, it is quite possible that already emaciated mussels from Lake Oologah (OK) may have reached lethal levels of tissue loss by that time in 2007. Poor physiologic condition due to extreme tissue mass loss in the Lake Oologah *D. polymorpha* population during the summers of 2006 and 2007 appeared to result in the anomalously reduced chronic thermal tolerance limits (<

26°C) recorded for this population during the summers of 2006 and 2007 compared to that of specimens from the cooler Hedges Lake, NY (= 28.0°C). The recent invasion of southwestern United States water bodies by *D. polymorpha* and *D. rostriformis bugensis* has caused much concern over their likely negative economic and ecological impacts in this region. The potential for dreissenid mussel populations to experience high-temperature induced density reductions or even eventual extirpation in the warm water bodies of the southwestern and southern United States may have important implications for both the eventual invasion and distribution of dreissenid mussels and their management and control in the southwestern United States. As such, the impact of high summer water temperatures on nutritional condition, growth, reproductive capacity, physiological limits and long-term survivorship in both *D. polymorpha* and *D. rostriformis bugensis* populations in the southwestern United States warrants further experimental attention.

Evolution of thermally-tolerant dreissenid populations in southwestern water bodies could be a source for their further invasion into the warm water bodies of the southern and southwestern United States previously presumed to be thermally resistant to dreissenid mussel invasion. It also poses major implications for thermal techniques utilized to mitigate and manage dreissenid mussel fouling in raw-water systems and for thermal spray washing mitigation of their fouling on recreational boat hulls and on other mussel-infested equipment transported overland. Indeed, this study suggests that adaptation of dreissenids to warmer southwestern water bodies may reduce the effectiveness of present thermal mitigation treatments to control their macrofouling in raw water systems. In addition, this study's demonstration of a positive relationship between both short-term temperature acclimation and longer-term temperature acclimatization on the chronic upper thermal tolerance limits of *D. polymorpha* appears to be well documented and may be characteristic of dreissenids in general (including *D. rostriformis bugensis*). These positive relationships may also reduce the efficacy of thermal mitigation treatments utilized in the warm southwestern regions of the United States.

The genetic evaluation of North American dreissenid invasion presented in this study also has implications for mitigation and containment techniques and strategies. The AFLP protocol utilized in this study, as well as other molecular techniques by other authors indicated a high level of genetic variation within North American populations of both *D. rostriformis bugensis* and *D. polymorpha*. The high levels of intrapopulation genetic variation relative to low levels of interpopulation variation make genetic differentiation of North American dreissenid populations difficult to assess. The general inability of this study to differentiate among intraspecific populations of *D. polymorpha* and *D. rostriformis bugensis*, and the high intrapopulation variability of AFLP marker data suggested that populations of dreissenid mussels recently established via the overland transport of individuals attached to boat hulls have not been subjected to genetic bottlenecks. Furthermore, given the recent invasion and low probability of multiple invasions for several of the sampled populations in this study, the lack of genetic bottlenecks likely resulted from the introduction of a large number of initial colonizers to these uninfested water bodies. The implied necessity for a large number of founding individuals to form sustainably reproducing *D. polymorpha* or *D. rostriformis bugensis* populations suggests that prevention and containment measures that thwart overland transport of mussels on recreational boats and other submerged equipment, including hot water, high pressure spraying, may not require absolute 100% efficacy in removing mussels to be effective in reducing the spread of dreissenid mussels in North America. If such techniques remove a high percentage of mussels from boat hulls or submerged equipment, leaving behind only a relatively few living individuals, the results of this study suggest that they would be unlikely to be able to successfully establish a new dreissenid population if transported to an uninfested water body.

Raw-water users such as electric power plants and water treatment plants in the southeastern and southwestern United States are presently not well prepared to deal with dreissenid mussel fouling and are likely to incur major operating and mussel mitigation costs as populations of *D. rostriformis bugensis* and *D. polymorpha* expand their ranges into these regions. This study presents evidence that the sensitive freshwater ecosystems of the southwestern and southeastern United States, from which dreissenids were once presumed to be thermally excluded, could support dense thermally-tolerant populations of both *D. polymorpha* and/or *D. rostriformis bugensis*. Unfortunately, most local, state and federal agencies and their local water body managers presently do not appear to be fully prepared or funded to implement the extensive and costly prevention and containment procedures required to limit the further range expansion of dreissenid mussels in southwestern water bodies and to deal with the resultant ecological and economic damage they entail. However, the results of this study also suggest that western U.S. water bodies may remain free of dreissenid mussels if a coordinated, integrated and region-wide prevention, containment and management plan is developed and adopted throughout the western states as detailed in the *Quagga-Zebra Mussel Action Plan for Western US Waters* by the Western Region Panel on Aquatic Nuisance Species (2009).