Watershed scale predictors of freshwater mussel distribution in Austin, Texas

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Abstract

Freshwater mussels are the most rapidly declining and understudied organism in North America. Of the 53 species in Texas, 15 are listed as state threatened, one is a candidate for federal protection, and 11 are currently petitioned for listing under the Endangered Species Act. Major threats include urbanization, nutrient loading, water withdrawal and diversion, and invasive species introduction. Understanding patterns of distribution and abundance of mussel populations in relation to water quality characteristics and regional land use is needed for conservation planning. A total of 15 species consisting of 633 live mussels and 1,032 spent valves were collected from 15 Austin-area watersheds. Four species *Lampsilis teres, Pyganodon grandis, Uniomerus tetralasmus and* Utterbackia *imbecillis* represent 96% of live specimens and 72% of spent valves. Changes in number of taxa, species diversity, dominance and evenness of live specimens, when compared to spent valves, suggests a temporal shift in composition to more tolerant, generalist species. Watersheds containing mussels had lower impervious cover ($P < 0.001$) and *E. coli* ($P < 0.01$) levels and higher levels of total suspended solids ($P < 0.05$) and turbidity ($P < 0.05$) than watersheds without live mussels or spent valves. These results suggest that urbanization, and resulting changes in hydrology and sediment composition are primary factors for mussel distribution in Austin, TX. The linkage of spatial patterns in mussel distribution to impervious cover at the catchment scale is an important tool for use in mussel conservation efforts with concomitant benefits to the rest of the aquatic ecosystem.

Introduction

Freshwater mussels are the most rapidly declining group of freshwater organisms in North America. Of the 53 species historically found in Texas, 15 are listed as state threatened, one is a candidate for federal protection, and 11 are currently petitioned for listing under the Endangered Species Act (Winemiller *et al.* 2010). Forty-six live unionid species have recently been recorded in Texas with only 48 believed to remain extant in the State (Burlakova *et al.* 2011b). Land use patterns associated with increased urbanization and changes to hydrology have been linked to freshwater mussel declines (Vaughn and Taylor 1999, Morales *et al.* 2006, Newton *et al.* 2008, Gangloff and Siefferman 2009, Stranko et al. 2010, Winemiller *et al.* 2010, Burlakova *et al.* 2011a, Burlakova *et al.* 2011b). Burlakova *et al.* (2011b) found that the presence of live mussels in Texas is negatively correlated to urbanization and the percentage of the watershed forested and evaporation rates best explains the differences in unionid assemblage structure between the four major Texas drainages. High flow disturbance events that cause substrate scouring and habitat destabilization have been shown to significantly decrease mussel species abundance and diversity (Strayer 1999, Newton *et al.* 2008, Randklev *et al*. 2009, Allen and Vaughn 2010). While high flow disturbance events are a natural, necessary function of healthy stream systems, in areas of growing urbanization the frequency of these events increases (Walsh *et al.* 2005). Morales *et al.* (2006) has found that increasing flow velocities may prevent the necessary recruitment of juvenile mussels and hinder the long-term survival of otherwise healthy mussel beds. Populations of rare mussels in Maryland were found to only inhabit streams with low impervious cover and urbanization influences (Stranko et al. 2010). Downstream of three highly urbanized tributaries in Alabama with degraded habitat and water quality, mussel abundance was substantially reduced (Gangloff and Siefferman 2009). Understanding the impacts of increased urbanization on the freshwater mussel community surrounding Austin is necessary for restoration and conservation efforts although at present, regulatory requirements for endangered species would not necessitate such actions. Funding for a mussel targeted restoration plan has also not been a department priority to date.

Freshwater mussels inhabit a variety of water-body types ranging from small rivers to large reservoirs. More commonly substrate stability, not composition, has been linked to higher density and diversity (Spooner 1999, Randklev et al. 2009, Allen and Vaughn 2010). Limiting substrate types consist of deep shifting sand, deep silt, and most boulder and cobble habitat (Howells et al. 1996). The most populated areas contain mud, sand, gravel, and cobble or a combination of these (Howells et al. 1996). Headwater streams, typically in the Texas Hill Country, support few mussels due to the lack of sufficient phytoplankton and other food sources (Howells et al. 1996). Unable to survive the extended periods of dewatering and low flow conditions of intermittent and ephemeral streams, most mussel species will be found in perennial systems (Howells et al. 1996). Due to their host fish requirements freshwater mussel distribution is greatly impacted by stream impoundments. Mussel extinction gradients have been observed directly downstream of an impoundment where species richness and abundance was low nearest the impoundment and increased with distance (Vaughn and Taylor 1999). Considerable stream lengths are required to overcome the impoundment effects with rare species occurring at sites farthest downstream (Vaughn and Taylor 1999). In Texas, mussel diversity in lotic systems was nearly double that of lentic, with no rare species observed in standing waters (Burlakova et al. 2011a).

In defining the community uniqueness of unionids, rare and endemic species are critical (Burlakova et al. 2011a). Continuing the replacement of lotic systems with lentic largely favors common species dramatically reducing habitat for rare and endemics (Burlakova et al. 2011a). To escape both low and high flow disturbance events mussels have adapted the ability to burrow in the sediment (Schwalb et al. 2009). Juvenile mussels can remain burrowed in the sediment for up to the first 4 years of their life; in general, mussel size and age is inversely proportional to depth in the sediment (Schwalb et al. 2009). Healthy mussel communities occur in multispecies assemblages with high interaction. These species-rich communities have been shown to positively impact one another increasing the likelihood of conserving rare species and maintaining overall high diversity (Vaughn et al. 2008).

Mussels perform many ecosystem functions critical for maintaining water quality. As filter feeders they have been shown to remove many environmental pollutants while acting as reliable water quality indicators (Howell *et al.* 1996). Presence of mussels has been related to reductions in ammonia, nitrate, phosphorous, and algae from the water column (Vaugn *et al.* 2006). Spooner *et al.* (2006) found that sediment surrounding mussels contained significantly higher levels of organic matter and macroinvertebrate densities. This is likely facilitated by the ability of freshwater mussels to alter resource availability (removing algae and organic matter) through nutrient excretion and biodeposition (Spooner *et al.* 2006). They have also been used in detection and monitoring of low level pesticide concentration in streams (Howell *et al.* 1996). Maintaining a diverse assemblage of freshwater mussels in Austin watersheds is an important component in preserving stream function and overall water quality. The objective of this study was to understand patterns of distribution and abundance of mussel populations in relation to water quality characteristics and regional land use in the City of Austin (COA). Specifically, this study examines how differences in mussel distribution at the sub-watershed level are impacted by percentage of impervious cover and water quality constituents (TSS, turbidity, pH, DO, conductivity, NH3, NO3, SO4, phosphorus, and *E. coli*). The utility of this knowledge will be in developing specific habitat restoration from current distribution information, targeting which locations are suitable for such restoration, as another planning indicator of overall ecosystem health, and in gaging recovery of damaged areas after project implementation. Should endangered species listing status change on any of our local mussels, or currently listed species be discovered, this study will allow a proactive response from the City.

Methods

Study Area

Sites were selected from the 45 watersheds utilized in the City of Austin's Environmental Integrity Index (EII). This long term monitoring program incorporates water quality, habitat and biological data from these creeks on a biannual basis. EII sites typically focus on headwater, middle reaches, and lower reaches of each watershed. Sixteen creeks were not surveyed due to geological characteristics (limestone bedrock substrate) that are typically not favorable to freshwater mussels. In addition to the creeks, two reservoirs of the Colorado River (Lake Austin and Lady Bird Lake) were surveyed for the presence of unionids. A major factor in the characteristics of the reservoir habitats sampled is that the flow of the lower Colorado River is regulated by the Lower Colorado River Authority (LCRA).

Survey Methods

A total of 26 creeks and 2 reservoirs were sampled from March 2007 to June 2010. An average of three locations was sampled from the headwater, middle reaches, and lower reaches of each watershed. Mussels were located using several methods: 1) visual; 2) snorkeling (Onion Creek); 3) shoreline collection of shells 4) tactile and 5) SCUBA. Typically most surveys employed more than one method (Strayer and Smith 2003).

Diversity Indices

Diversity indices were calculated to make comparisons between watersheds containing live mussels and spent valves to those watersheds void of mussels. The following indices were calculated using standard curatorial software commonly applied in mussel studies (Oyvind Hammer 2011).:

- Number of taxa (*S*)

- Total number of individuals (*n*)

- Dominance = 1-Simpson index. Ranges from 0 (all taxa are equally present) to 1 (one taxon dominates the community completely).

  $D = \sum_i \left(\frac{n_i}{n}\right)^2$ where n_i is number of individuals of taxon *i*.

- Simpson index 1-*D*. Measures 'evenness' of the community from 0 to 1. Note the confusion in the literature: Dominance and Simpson indices are often interchanged!

- Shannon index (entropy). A diversity index, taking into account the number of individuals as well as number of taxa. Varies from 0 for communities with only a single taxon to high values for communities with many taxa, each with few individuals.

  $H = -\sum_i \frac{n_i}{n} \ln \frac{n_i}{n}$

- Buzas and Gibson's evenness: e^H/S

Statistical Analysis
Conventional water quality parameters measured by the City of Austin during their annual Environmental Integrity Index (EII) were averaged for each watershed (n=3 sites per watershed) sampled. Watersheds containing live specimens, spent valves, or both were compared to those containing no live mussels or spent valves in order to determine if presence or absence of mussels at the sub-watershed scale is associated with land use or water quality parameters. Student's t-tests were performed using PAST version 2.09 to test the hypothesis that there are no significant differences between watersheds that contain mussels or spent valves to watersheds that are void of mussels or spent valves (Oyvind Hammer 2011).

Results

A total of 15 species consisting of 633 live mussels and 1,014 spent valves were collected from 15 Austin-area watersheds (Figure 1-2). Four species *Lampsilis teres*, *Pyganodon grandis*, *Uniomerus tetralasmus and Utterbackia imbecillis* represent 96% of live specimens and 72% of spent valves. Number of taxa, species diversity (Simpson and Shannon) and evenness indices for live specimens were lower when compared to spent valves (Table 1). The dominance indice for live specimens was higher than that of spent valves (Table 1). Watersheds containing mussels had lower impervious cover ($P < 0.001$) and *E. coli* ($P < 0.01$) levels and higher levels of total suspended solids ($P < 0.05$) and turbidity ($P < 0.05$) than watersheds without live mussels or spent valves (Figure 3). Dissolved oxygen (DO), conductivity, pH, and nutrient concentrations were not significantly related to mussel distribution at the sub-watershed scale (Figure 3).

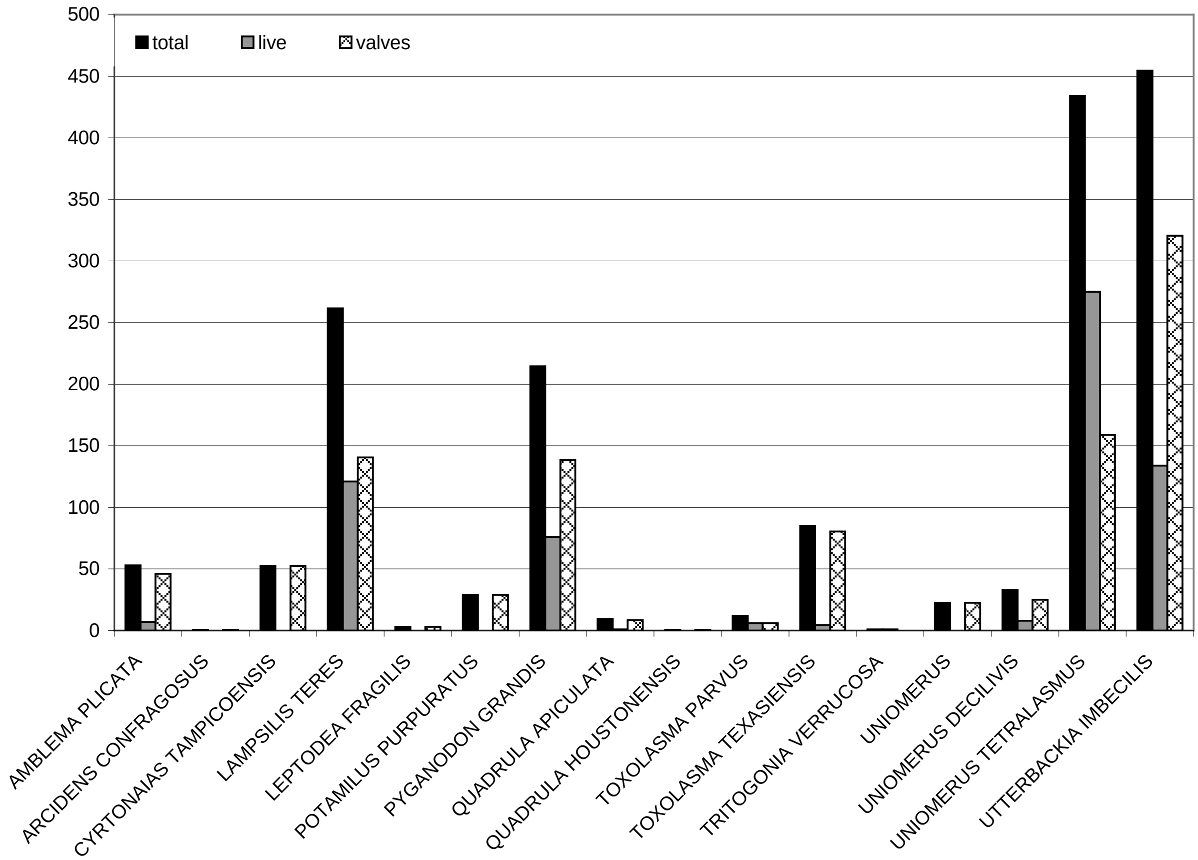

Figure 1: Total number of all unionid species collected from Austin, TX 2007-2010. Black bars indicate total for the species (live organisms and valves), grey bars indicate live specimens only, and patterned bars indicate spent valves collected.

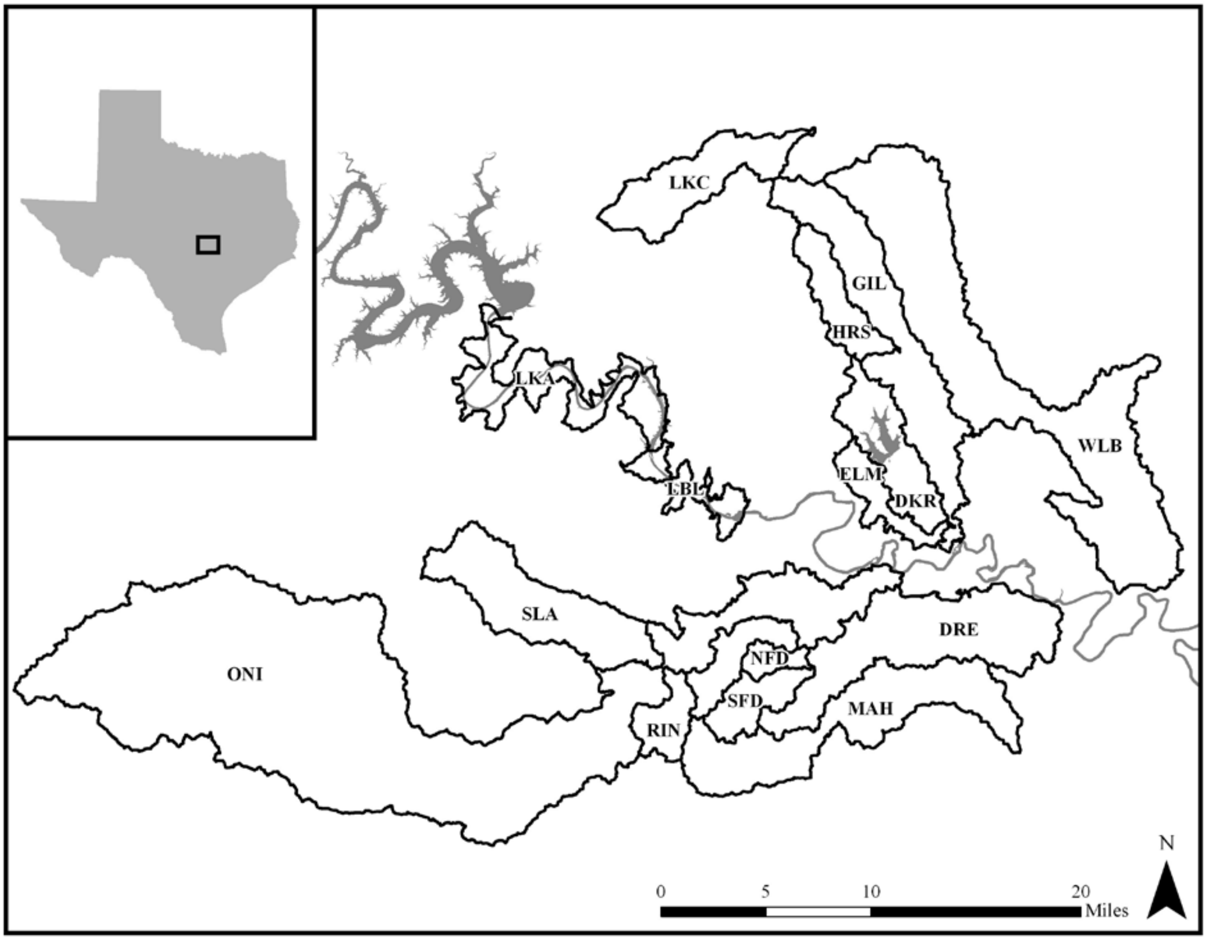

Figure 2: Austin, TX creeks where freshwater mussels were collected 2007-2010. Labeled creeks contained freshwater mussels. ONI = Onion, SLA = Slaughter, RIN = Rinard, NFD = North Fork Dry, SFD = South Fork Dry, MAH = Maha, DRE = Dry, LKA = Lake Austin, LBJ, Lady Bird Lake, DKR = Decker, HRS = Harris Branch, LKC = Lake, GIL = Gilleland, and WLB = Wilbarger.

Table 1: Diversity indices comparison for live vs. spent (shells) freshwater mussels collected 2007-2010 in Austin, TX creeks. Lake Austin and Lady Bird Lake were not used in this analysis.

	Live	**Shell**
Taxa_S	10	14
Individuals	633	1014
Dominance_D	0.2849	0.1757
Shannon_H	1.463	1.994
Simpson_1-D	0.7151	0.8243
Evenness_e^H/S	0.432	0.5246

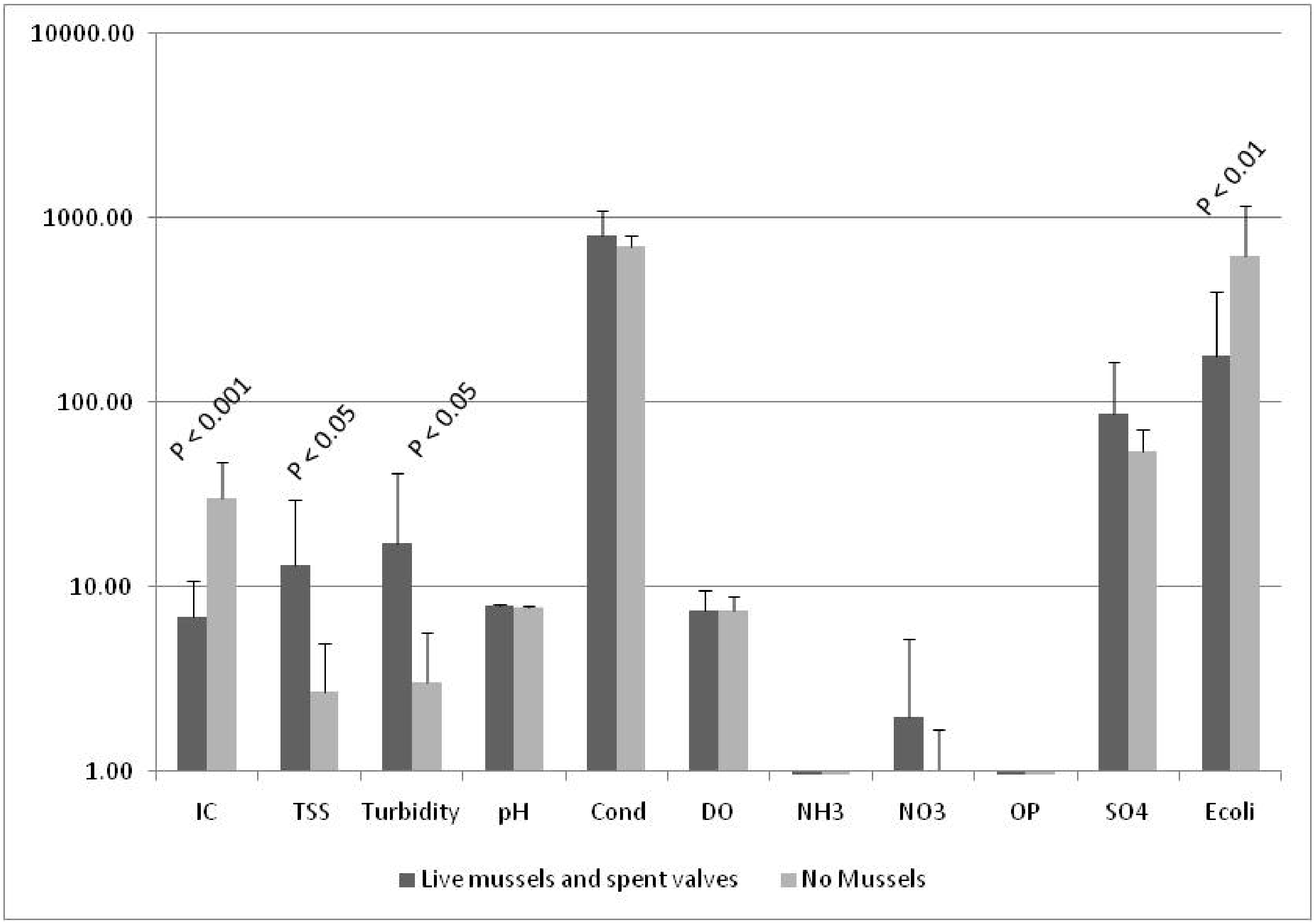

Figure 3: Comparison of water quality parameters between watersheds with live mussels and spent valves to watersheds with no mussels present. Darker bars indicate watersheds where either live mussels, spent valves or both were collected. Lighter bars indicate watersheds were no live mussels or spent valves were collected. Lake Austin and Lady Bird Lake were not used in this analysis. Significant differences are denoted by associated p-value above.

Discussion

Status of Freshwater Mussels in Austin

Freshwater mussels are good indicators of water quality due to their longevity, sedentary movement, and shell record (Grabarkiewicz and Davis 2008**)**. The longevity of freshwater mussels affords biologists the ability to examine changes on a yearly to decade scale. Their inability to move and respond to changes within their immediate environment guarantees a constant exposure to changing water quality conditions. Mussel shells are persistent in the environment allowing for temporal analysis when long term data is lacking. Intensive monitoring by the City of Austin (COA) on freshwater mussels began in 2007 with extremely limited data collected prior. Comparisons between the live mussel and spent valves from this monitoring indicate a significant overall shift in community composition in our water bodies. Four species *Lampsilis teres* (Yellow Sandshell), *Pyganodon grandis* (Giant Floater), *Uniomerus tetralasmus* (Pondhorn*) and Utterbackia imbecillis (*Paper Pondshell*)* represent 96% of live specimens and 72% of spent valves collected. Yellow Sandshell, Giant floater and Paper Pondshell are some of the most common and tolerant species in Texas (Grabarkiewicz and Davis 2008, Burlakova *et al.* 2011b). Pondhorn is considered a vagrant species (isolate at the edge of its range) in Texas and is not considered a high priority for conservation (Burlakova *et al.* 2011b). A 14% increase in these generalist species coupled with a rise in the dominance index indicates reduced overall health of the freshwater mussel population in Austin over the past few decades. Healthy mussel communities occur in multispecies (diverse) assemblages with high interaction (Vaughn *et al.* 2008). With reduced diversity and species evenness our remaining live populations are more vulnerable to extirpation. Therefore, restoration efforts should be designed for whole mussel communities rather than individual species to improve species interactions and ecological function (Vaughn *et al.* 2008).

Environmental Factors and Mussel Distribution

To further understand the observed decline in Austin mussel diversity over past decades, comparisons in land use and environmental variables among watersheds were examined. Watersheds containing mussels had lower impervious cover and higher total suspended solids and turbidity than watersheds without live mussels or spent valves. It is well documented that increases in impervious cover within a watershed can drastically alter the hydrology and sediment stability within a stream. Walsh *et al.* (2005) linked a rise in the percentage of impervious cover within a watershed to increases in overland flow, erosion, magnitude of high flows, nutrients, water temperature and sediment scouring of the stream. All of these factors have been linked to declines in freshwater mussel abundance and diversity (Vaughn and Taylor 1999, Morales *et al.* 2006, Newton *et al.* 2008, Gangloff and Siefferman 2009, Stranko et al. 2010, Winemiller *et al.* 2010, Burlakova *et al.* 2011a, Burlakova *et al.* 2011b). Most recently, a study of mussels throughout Texas showed a negative correlation between presence of live mussels and degree of urbanization in the watershed with percentage of the forested area as the best explanatory variable (Burlakova *et al.* 2011b). The Sabine Province, consisting of the Sabine, Neches, Trinity, and San Jacinto drainages, has the highest percentage of forested landscape and is considered the region with the most robust Texas unionid diversity (Burlakova *et al.* 2011b). The Sabine Province has little urbanization and few stream impoundments.

Increased scouring and sheer stress of stream sediments has been shown to negatively impact mussel fecundity at all life stages. Morales *et al.* (2006) has found that increasing flow velocities may prevent recruitment of juvenile mussels and hinder the long-term survival of healthy mussel beds. Substrate stability including that of particulates of various size classes during high flows is believed to be the most important physical variable connected to hydrology that is limiting to mussel abundance and diversity (Allen and Vaughn 2010). Local data is consistent with this conclusion as the amount of suspended solids in the water column (TSS) is higher in watersheds containing mussels (Figure 3). These findings identify streams containing mussels in Austin as those having fewer scouring events and more natural flow patterns. The wider particle size distribution incorporating solids in TSS (<1.5 µm) is apparently better for mussel presence than a narrow range of larger cobble and bedrock as found in scoured urban streams. In general, the preferred areas for mussels are those which contain a combination of mud, sand and gravel substrates (Howells et al. 1996)

Conservation Priorities

Endemic species (belonging to or native to a particular area) are critical in defining the uniqueness of unionid communities in Central Texas and are a key component of healthy functioning stream systems (Burlakova *et al.* 2011a, Burlakova *et al.* 2011b). Diverse mussel beds within a stream have been shown to perform ecosystem functions critical for maintaining water quality (Howell *et al.* 1996, Vaughn *et al.* 2006, Spooner *et al.* 2006). To preserve these ecosystem services provided by freshwater mussels it is first necessary to rank rare and endemic species with the highest conservation priority. Of the seven endemic species in Texas, six are historically found in the Colorado River basin (Burlakova *et al.* 2011b). Due to the number of endemic species, Central Texas watersheds (Colorado, Guadalupe, and San Antonio rivers) have been be recognized internationally as a priority for mussel conservation (Burlakova *et al.* 2011a). Rare and endemic species have been shown to benefit from living in species-rich communities (Vaughn *et al.* 2008): therefore focusing conservation on the community of existing mussel beds while promoting stable habitat for the formation of new ones is the best way to protect the water quality and mussel diversity of Central Texas. It is recommended that these conservation strategies be considered and incorporated when possible in long range program and project plans in watershed protection of Austin. More localized opportunities may also occur sooner depending on locations of multipurpose integrated projects.

Future Research

Additional surveys to document the existence of rare and endemic freshwater mussel species within the City of Austin's jurisdiction would be necessary prior to establishing a specific restoration and conservation plan for unionids. Intensive surveys on the Lower Colorado River downstream of longhorn dam are also recommended in order to evaluate if source populations and adequate recruitment exists. Further investigation into the impacts of urbanization on mussel abundance, diversity and distribution in Austin is recommended to get the most value from restoration efforts. Specifically, if a threshold in increased development (% impervious cover) where mussel diversity is drastically degraded, projects can be targeted to deal with these areas. In addition, determining if there is a cause effect relationship between mussel density and reduced *E. coli* levels in the water column of streams could result in a useful tool to examine the accumulated long term effects of transient bacteria contamination events Along this same vein, an evaluation of effluent effects including nutrients, disinfection residuals and bacteria regrowth on mussels communities would benefit the City's efforts to promote responsible wastewater treatment, land application, and discharge in watersheds of local interest. Finally, taking a proactive approach to resolving these questions in advance will prepare the City to take conservation actions should regulatory priorities necessitate them and funding become available.

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