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# Changes in the mussel fauna of the middle Red River drainage: 1910 - present.

Caryn C. Vaughn[1]

*Oklahoma Biological Survey and Department of Zoology, University of Oklahoma, 111 E. Chesapeake Street, Norman, OK 73019*

*ABSTRACT*: Mussels were sampled at 19 sites in the Red River drainage of Oklahoma and Texas that had been sampled historically in the 1910s and 1960s. Species richness declined at 89% and increased at 11% of the sites. Between the 1910s and 1990s the mean number of species per site dropped from 7.0 (±1.46) to 5.16 (±1.14). Changes in species richness between sites sampled in the 1910s versus the 1990s were statistically significant ($t$ = 3.539, df = 13, P = 0.004). Changes in species richness between sites sampled in the 1960s and 1990s were not significant ($t$ = 1.623, df = 5, P = 0.0165). Of the mussel species found historically and in the present survey, 86% occurred at fewer sites than in the past. Local extinction rates were significantly greater than local colonization rates ($t$ = 4.129, df = 15, P = 0.001), indicating that mortality of mussels is significantly exceeding recruitment in the region.

**Keywords:** Bivalvia, Unionidae, river, distribution, species richness, extinction, colonization.

It is well known that the global freshwater mussel fauna is highly threatened and in decline. In many cases the extent of this decline has not been documented because of a lack of historical data. The Red River drainage of south-central and southeastern Oklahoma is an area of high mussel diversity for which there are reliable historical data on mussel distributions. In the early 1900s Frederick B. Isely, a biologist working for the US Bureau of Fisheries, conducted a comprehensive distributional survey of the mussel fauna of the middle Red River basin focusing on the eastern half of Oklahoma (Isely 1924, Shepard 1982, Gordon 1988). In the 1960's Barry D. Valentine and his Invertebrate Zoology classes from the University of Oklahoma Biological Station extensively collected from tributaries to the Red River in eastern Oklahoma (Valentine and Stansbery 1971). The objective of this study was to revisit these sites and assess the current status of the Red River basin mussel fauna.

## Methods

Isely sampled 20 sites on 9 tributaries to and the mainstem of the Red River from 1910 - 1912. Six of these stations have subsequently been flooded by impoundments, leaving 14 intact sites. Valentine and Stansbery (1971) collected from 9 tributary sites in 1965-1968, including a site that had previously been sampled by Isely. One of Valentine's sites was destroyed by an impoundment. From 1993-1995, I resampled 19 of these historical sites; 14 sampled by Isely (1924) and 6 sampled by Valentine and Stansbery (1971) (with one site sampled by both researchers) (Fig.1).

Mussels were sampled at each site using a timed search. A timed search is the most common technique for collecting information on mussel abundance, and has been shown to reliably estimate total species richness and locate rare species (Vaughn *et al.* 1997, Strayer *et al.* 1997). Timed surveys were conducted by searching the entire site for a minimum of 1 h by 2 experienced surveyors. Surveyors systematically searched an area wearing a mask and snorkel and collected mussels by hand. Mussels with either part of the shell or their siphon exposed at the surface were located by both sight and feel; when a patch of mussels was located, the surveyor also dug in the substrate for buried mussels. SCUBA was used to search in deeper areas (> 75 cm). Collected mussels were placed in a canvas bag underwater and removed to shore. Individual mussels were identified on shore (Table 1), and returned to the stream alive after all sampling was completed. This technique is described in greater detail in Vaughn *et al.* (1997).

Historical versus present-day species richness at sites were compared using paired $t$-tests (Sokal and Rohlf 1997). Local (=patch) extinction ($p_e$) and colonization rates ($p_c$) were calculated for each mussel species following Gotelli (1995) as:

[1] For correspondence contact C.C. Vaughn. (Email: cvaughn@ou.edu)

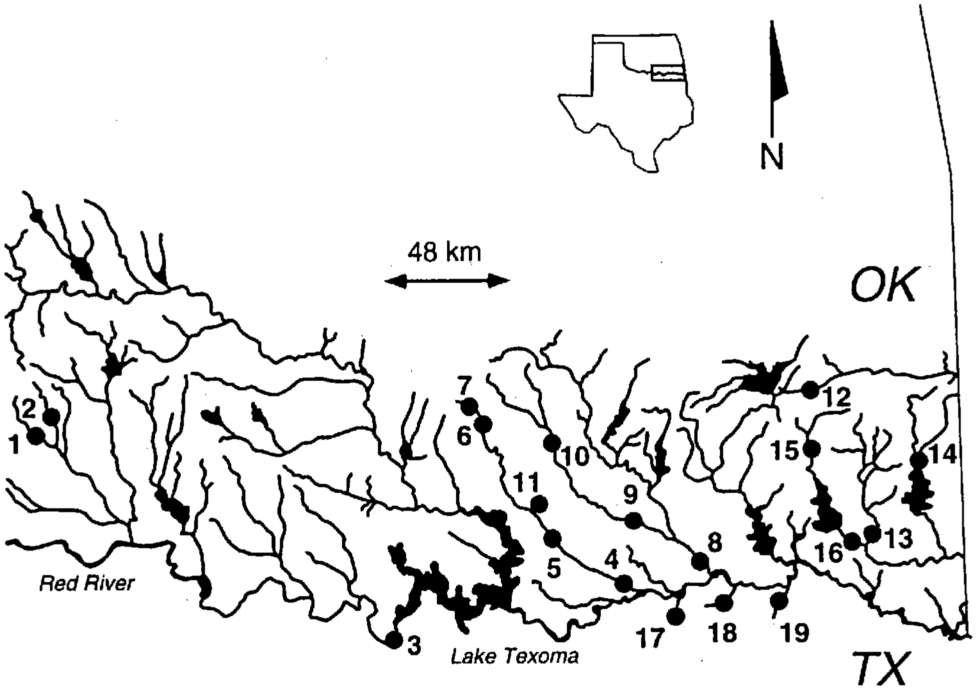


**Figure 1.** Historical sites sampled in the Red River drainage of Oklahoma and Texas: (1) West Cache Creek, (2) Cache Creek, (3) Red River, (4) Lower Blue River, (5) Blue River at Armstrong, (6) Blue River 0.4 km N of Milburn, (7) Blue River 3 km N of Milburn, (8) Lower Boggy Creek, (9) Clear Boggy Creek at Boswell, (10) Clear Boggy Creek at Olney, (11) Buzzard Creek (tributary to the Blue River), (12) Kiamichi River, (13) Glover Creek, (14) Mountain Fork River, (15) Little River at Cloudy, (16) Little River at Garvin, (17) Bois D'Arc Creek, (18) Saunders Creek, and (19) Big Pine Creek.

$p_e$ = number of times a species was found historically but absent in present day collections divided by the sum of the number of local extinctions plus the number of times the species did not go locally extinct. The $p_e$ value ranges from 0-1 and represents the probability that a population at a site will go extinct.

$p_c$ = number of times a species was presently found but not found historically divided by the sum of the number of colonizations plus the number of times colonization events did not occur. The $p_c$ value ranges from zero to one and represents the probability that a site will be colonized.

Local extinction and colonization rates were calculated only for the subset of sites originally sampled by Isely (1924) and then re-sampled for this project.

## Results

Species richness declined at 17 of the 19 sites (89%) and increased at 2 of the 19 sites (11%) (Fig. 2). Between the 1910s and 1990s the mean number of species per site dropped from 7.0 (±1.46) to 5.16 (±1.14). Changes in species richness between sites sampled in the 1910's versus the 1990's were statistically significant ($t$ = 3.539, df = 13, P = 0.004). Changes in species richness between sites sampled in the 1960's and 1990's were not significant ($t$ = 1.623, df = 5, P = 0.0165) (Fig. 2).

Colonization rates for all species in the system were quite low. Most sites only experienced extinctions during the 80-y time period (Table 1). Mean local extinction rates significantly exceeded mean local colonization rates ($t$ = 4.129 df = 15, P = 0.001) (Fig. 3).

Thirty-four species were found in the historical surveys and 29 during the 1990s (Table 1). Only living mussels were counted (*i.e.*, neither fresh dead nor relict shells were used in species tallies). Several species found historically were completely extirpated from the suite of sites sampled in the 1990s: *Leptodea leptodon* (Rafinesque 1820), *Elliptio dilatata* (Rafinesque 1820), *Lasmigona costata* (Rafinesque 1820), *Pleurobema rubrum* (Rafinesque, 1820), *Truncilla donaciformis* (Lea, 1828), and *Uniomerus*

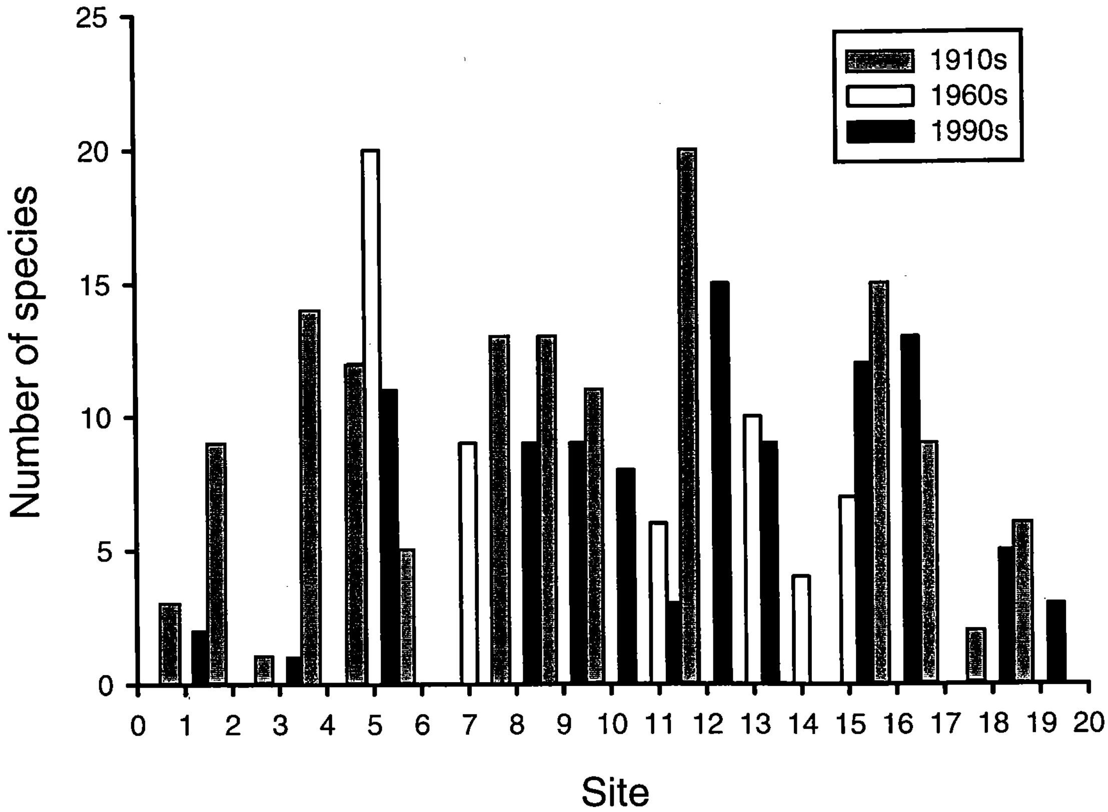


**Figure 2.** Historical and present-day species richness at the 19 sites.

*tetralasmus* (Say, 1831) Of the mussel species found both historically and in the present survey, 86% occurred at fewer sites than historically (Table 1). Three species found in the historical surveys occurred at a greater number of sites in the present survey: *Lampsilis cardium* (Rafinesque 1820), *Obliquaria reflexa* (Rafinesque 1820), and *Quadrula cylindrica* (Say, 1817). In addition, three species (i.e., *Villosa arkansasensis* (Lea, 1862), *V. iris* (Lea, 1859), *V. lienosa* (Conrad, 1834) were found that were not reported from the historical collections.

## Discussion

The results of this study indicate that mussels are declining in the middle Red River drainage. This trend is apparent at multiple ecological scales: at the community level through examination of species richness patterns; at the species level through examination of individual species trends; and at the population level through examination of local extinction and colonization rates.

Caution should be used when inferring temporal changes in mussel populations based on presence-absence data from a limited number of sites (Strayer 1999). However, the conclusions derived from the data in this study are supported by several other studies in the region. Three Red River tributaries, the Blue, Kiamichi, and Little rivers have been quantitatively surveyed, in most cases from the headwaters to their confluence with the Red River.

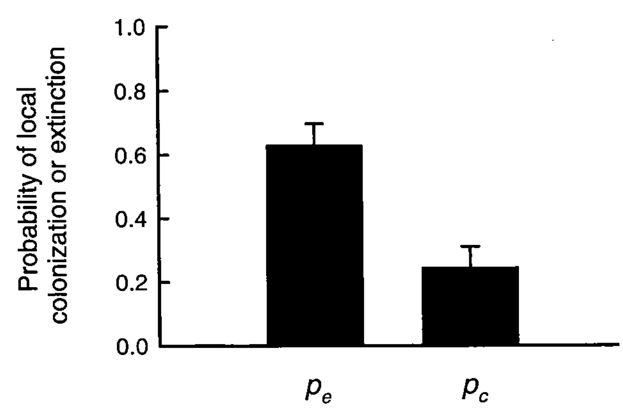


**Figure 3.** Mean local colonization and extinction rates (± SD).

**Table 1.** Current and historical mussel occurrences in the Red River drainage. I = Isely, V = Valentine and Stansbery, P = present (this study). All data are for living mussels. Numbers correspond to the sites shown in Figure 1. Sites are as follows: (1) West Cache Creek, (2) Cache Creek, (3) Red River, (4) Lower Blue River, (5) Blue River at Armstong, (6) Blue River 0.4 km N. of Milburn, (7) Blue River 3 km N. of Milburn, (8) Lower Boggy Creek, (9) Clear Boggy at Boswell, (10) Clear Boggy at Olney, (11) Buzzard Creek, (12) Kiamichi River at Tuskahoma, (13) Glover Creek, (14) Mountain Fork River, (15) Little River at Cloudy, (16) Little River at Garvin, (17) Bois D'arc Creek, (18) Saunders Creek, and (19) Big Pine Creek.

| | **(1)** | | **(2)** | | **(3)** | | **(4)** | | **(5)** | | | **(6)** | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Species** | **I** | **P** | **I** | **P** | **I** | **P** | **I** | **P** | **I** | **V** | **P** | **I** | **P** |
| *Actinonaias ligamentina* | | | | | | | | | | | | | |
| *Amblema plicata* | | | | | | | X | | X | X | X | X | |
| *Arkansia wheeleri* | | | | | | | | | | | | | |
| *Ellipsaria lineolata* | | | | | | | | | | | | | |
| *Elliptio dilatata* | | | | | | | | | | | | | |
| *Fusconaia flava* | | | | | | | X | | X | X | X | X | |
| *Lampsilis cardium* | | | | | | | X | | | X | X | X | |
| *Lampsilis siliquoidea* | | | | | | | | | X | X | X | X | |
| *Lampsilis teres* | | X | X | | | | X | | X | X | X | | |
| *Lasmigona complanata* | | | | | | | X | | | X | | | |
| *Lasmigona costata* | | | | | | | | | | | | | |
| *Leptodea fragilis* | | | X | | | | X | | X | X | | | |
| *Leptodea leptodon* | | | | | | | | | | | | | |
| *Ligumia subrostrata* | | | | | | | | | | | | | |
| *Megalonaias nervosa* | | | | | | | X | | | | | | |
| *Obliquaria reflexa* | | | | | | | | | | X | X | | |
| *Obovaria jacksoniana* | | | | | | | | | | | | | |
| *Plectomerus dombeyanus* | | | | | | | | | | | | | |
| *Pleurobema rubrum* | | | | | | | | | | | | | |
| *Pluerobema sintoxia* | | | | | | | | | | | | | |
| *Potamilus ohiensis* | | X | X | | X | X | | | | X | | | |
| *Potamilus purpuratus* | | | X | | | | X | | | X | X | | |
| *Ptychobranchus occidentalis* | | | | | | | | | X | | X | | |
| *Pyganodon grandis* | | | | | | | | | | X | | | |
| *Quadrula cylindrica* | | | | | | | | | | | | | |
| *Quadrula pustulosa* | | | X | | | | X | | X | X | X | X | |
| *Quadrula quadrula* | | | X | | | | X | | X | X | X | | |
| *Strophitus undulatus* | | | | | | | | | | | | | |
| *Toxolasma parvus* | X | | | | | | X | | X | X | | | |
| *Toxolasma texasiensis* | | | | | | | | | | | | | |
| *Tritogonia verrucosa* | | | X | | | | X | | X | X | X | | |
| *Truncilla donaciformis* | | | X | | | | X | | X | X | | | |
| *Truncilla truncata* | | | | | | | X | | X | X | | | |
| *Uniomerus tetralasmus* | X | | X | | | | | | | X | | | |
| *Utterbackia imbecillis* | X | | | | | | | | | X | | | |
| *Villosa arkansasensis* | | | | | | | | | | | | | |
| *Villosa iris* | | | | | | | | | | | | | |
| *Villosa lienosa* | | | | | | | | | | | | | |
| *Villosa* sp. | | | | | | | | | | X | | | |

**Table 1.** Current and historical mussel occurrences in the Red River drainage, continued.

| Species | (7) | | (8) | | (9) | | (10) | | (11) | | (12) | | (13) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | V | P | I | P | I | P | I | P | V | P | I | P | V | P |
| *Actinonaias ligamentina* | | | | | | | | | | | X | X | X | X |
| *Amblema plicata* | X | | X | X | X | X | X | X | | | X | X | X | X |
| *Arkansia wheeleri* | | | | | | | | | | | X | X | | |
| *Ellipsaria lineolata* | | | | | | | | | | | X | X | | |
| *Elliptio dilatata* | | | | | | | | | | | X | | | |
| *Fusconaia flava* | X | | X | X | X | X | X | X | | | | X | X | X |
| *Lampsilis cardium* | X | | | X | X | X | | X | | | | X | | X |
| *Lampsilis siliquoidea* | | | X | | | | X | | X | X | X | X | | |
| *Lampsilis teres* | X | | X | X | X | X | X | X | | | X | | | |
| *Lasmigona complanata* | | | | | | | | | | | | | | |
| *Lasmigona costata* | | | X | | | | | | | | | | X | |
| *Leptodea fragilis* | X | | X | | X | | X | | | | | X | | |
| *Leptodea leptodon* | | | | | | | | | | | X | | | |
| *Ligumia subrostrata* | | | | | | | | | X | X | | | | |
| *Megalonaias nervosa* | | | X | X | X | | X | | | | | | | |
| *Obliquaria reflexa* | | | X | X | | X | X | | | | X | X | | |
| *Obovaria jacksoniana* | | | | | | | | | | | X | X | X | |
| *Plectomerus dombeyanus* | | | | | | | | | | | | | X | |
| *Pleurobema rubrum* | | | | | | | | | | | X | | | |
| *Pluerobema sintoxia* | | | | | | | | | | | | | | |
| *Potamilus ohiensis* | | | | | | | | | | | | | | |
| *Potamilus purpuratus* | | | X | X | X | X | X | X | | | X | X | | |
| *Ptychobranchus occidentalis* | X | | | | | | | | X | | X | | | X |
| *Pyganodon grandis* | | | | | | | | | | | X | | X | |
| *Quadrula cylindrica* | | | | | | | | | | | | | | X |
| *Quadrula pustulosa* | X | | X | X | X | X | X | X | | | X | X | X | X |
| *Quadrula quadrula* | | | X | | X | X | X | X | | | X | X | | |
| *Strophitus undulatus* | | | | | X | | | | | | X | | X | |
| *Toxolasma parvus* | | | | | | | | | X | X | | | | |
| *Toxolasma texasiensis* | | | | | | | | | | | | | | |
| *Tritogonia verrucosa* | X | | X | X | X | X | X | X | | | X | X | X | X |
| *Truncilla donaciformis* | X | | | | X | | | | | | | | | |
| *Truncilla truncata* | | | X | | X | | | | | | X | X | | |
| *Uniomerus tetralasmus* | | | | | | | | | | | | | | |
| *Utterbackia imbecillis* | | | | | | | | | X | | X | | | |
| *Villosa arkansasensis* | | | | | | | | | | | | | | X |
| *Villosa iris* | | | | | | | | | | | | | | |
| *Villosa lienosa* | | | | | | | | | | | | | | |
| *Villosa* sp. | | | | | | | | | X | | | | | |

**Table 1.** Current and historical mussel occurrences in the Red River drainage, continued.

| Species | (14) | | (15) | | (16) | | (17) | | (18) | | (19) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | V | P | V | P | I | P | I | P | I | P | I | P |
| *Actinonaias ligamentina* | | | | | X | X | | | | | | |
| *Amblema plicata plicata* | | | X | X | X | X | X | | | | | |
| *Arkansia wheeleri* | | | | | | | | | | | | |
| *Ellipsaria lineolata* | | | | | X | X | | | | | | |
| *Elliptio dilatata* | | | | | | | | | | | | |
| *Fusconaia flava* | X | | X | X | | X | | | | | | |
| *Lampsilis cardium* | | | | X | | | | | | | | |
| *Lampsilis siliquoidea* | | | | X | X | | | | | | X | |
| *Lampsilis teres* | | | | | X | | X | | X | | X | |
| *Lasmigona complanata* | | | | | | X | X | | | | | X |
| *Lasmigona costata* | | | | | | | | | | | | |
| *Leptodea fragilis* | | | | | | X | X | | | | X | |
| *Leptodea leptodon* | | | | | | | | | | | | |
| *Ligumia subrostrata* | | | | X | | | | | | | X | |
| *Megalonaias nervosa* | | | | | | | | | | | | |
| *Obliquaria reflexa* | | | | | X | X | | | | X | | X |
| *Obovaria jacksoniana* | | | | | X | X | | | | | | |
| *Plectomerus dombeyanus* | | | | | X | X | | | | | | |
| *Pleurobema rubrum* | | | | | X | | | | | | | |
| *Pluerobema sintoxia* | | | | | | | | | | | | |
| *Potamilus ohiensis* | | | | | | | X | | X | | X | |
| *Potamilus purpuratus* | | | | | X | | X | | | | | |
| *Pthychobranchus occidentalis* | X | | | | | X | | | | | | |
| *Pyganodon grandis* | X | | X | | | | | | | X | | |
| *Quadrula cylindrica cylindrica* | | | | | X | X | | | | | | |
| *Quadrula pustulosa pustulosa* | | | X | X | X | X | X | | | X | | |
| *Quadrula quadrula* | | | X | | X | X | X | | | X | | X |
| *Strophitus undulatus* | | | | X | | | | | | | | |
| *Toxolasma parvus* | | | | X | | | | | | | X | |
| *Toxolasma texasiensis* | | | | | | | | | | | | |
| *Tritogonia verrucosa* | X | | X | X | | | | | | | | |
| *Truncilla donaciformis* | | | | | X | | X | | | | | |
| *Truncilla truncata* | | | | | X | | | | | X | | |
| *Uniomerus tetralasmus* | | | | | | | | | | | | |
| *Utterbackia imbecillis* | | | X | | | | | | | | | |
| *Villosa arkansasensis* | | | | X | | | | | | | | |
| *Villosa iris* | | | | X | | | | | | | | |
| *Villosa lienosa* | | | | X | | | | | | | | |
| *Villosa sp.* | | | | | | | | | | | | |

Each of these studies indicate that unionids are in overall decline. Mussels have been completely extirpated from much of the Blue River (Vaughn 1997), even though they were quite abundant during in the 1960s (Valentine and Stansbery 1971). Similarly, mussels (both common and rare species) have been extirpated from long stretches below dams in the Little River (Vaughn and Taylor 1999). The Kiamichi River has been identified by The Nature Conservancy as one of the critical watersheds in North America for protecting freshwater biodiversity (Master *et al.* 1998), based largely on its mussel fauna (Vaughn *et al.* 1996). Yet, even in this exemplary healthy river mussel populations are declining. Forty-three percent of the historically known subpopulations of the endangered Ouachita rock pocketbook mussel, *Arkansia wheeleri* (Ortmann and Walker, 1912), have been extirpated from the Kiamichi River (Vaughn and Pyron 1995).

When measured at the appropriate spatial and temporal scales, $p_e$ and $p_c$ are excellent indicators of extinction and colonization potential (Angermeier 1994, Gotelli 1995). However, these formulas can underestimate rates if multiple extinctions and recolonizations occur over the sampling period (Diamond and May 1977). That is very unlikely in this study because the 80 year gap between Isely's (1924) collections and my collections represent only a few mussel generations. Isely's (1924) field techniques were quite quantitative for his time. For example, he discusses the use and value of replicate samples and the problems using mark/recapture techniques (Isely 1914, Gordon 1988). However, Isely sampled by wading and picking up mussels and I sampled by systematically snorkeling sites and by digging into the substratum. Because my sampling method was more rigorous than Isely's, any sampling error should be in the direction of my finding more species than Isely. That is, there is an increased probability that I might locate species he missed and overestimate colonization rates, but a very low probability that I would miss species and underestimate extinction rates. Given this potential sampling error, the gap between local extinction and colonization rates is probably even greater than reported here.

The discrepancy between local colonization and extinction rates underscores the ultimate cause of mussel decline in the Red River drainage and globally: mussel mortality at individual sites is exceeding recruitment. As long as this holds true mussels will continue to decline. The proximate causes underlying high mussel mortality, primarily habitat change and degradation, have been well-addressed by other papers in this symposium. The factors limiting recruitment include not only habitat changes and degradation impacting the mussels themselves, but also their fish hosts (Haag and Warren 1997, Vaughn and Taylor 2000).

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