CHAPTER FOUR

# Prehistoric Biogeography and Conservation Status of Threatened Freshwater Mussels (Mollusca: Unionidae) in the Upper Trinity River Drainage, Texas

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Historically, North America contained the most diverse and abundant population of freshwater mussels in the world, with nearly 300 species (Neves 1993). Unfortunately, habitat destruction stemming from sedimentation, impoundment of streams and rivers, release of environmental contaminants, and the introduction of invasive species has reduced this number (Lydeard et al. 2004; Neck 1982a; Strayer 1999). Current estimates suggest that 12% of the mussel species endemic to North America are now extinct and 23% are threatened or endangered (Galbraith et al. 2008 and references therein). The 52 species described in Texas have also been impacted, and many local streams and rivers are unable to support mussel populations at levels that existed in the past (Howells et al. 1996, 1997). As a consequence, 15 Texas species have recently been listed as threatened, and 11 of these are now the subjects of petitions for





protection under the Endangered Species Act (ESA) (Texas Parks and Wildlife Department [TPWD] 2009).

Listing a species under the ESA requires that decisions be made using the "best scientific and commercial (trade) data available" (Nicholopoulos 1999:8). For these species, "substantial information" using biological and biogeographic (past and present) data must demonstrate one of the following:

1. The destruction, modification, or curtailment of habitat or range
2. Overutilization for commercial, recreational, scientific, or educational purposes
3. Population decline related to disease or predation
4. Inadequacy of existing regulatory mechanisms for protecting existing populations
5. Natural or anthropogenic factors affecting a species' continued existence (US Fish and Wildlife Service 2009)

Presumably, this would also be the case for conservation listings at state or local levels. Unfortunately, for both rare and common species, modern and historical data regarding ecological preferences and biogeographic distributions are incomplete at best (Brown and Lomolino 1998; National Native Mussel Conservation Committee 1998).

For unionids, the absence of basic biological data stymies conservation efforts. As a result, a national strategy was established in 1997 to help organizations identify tasks needed for the long-term conservation of mussels (NNMCC 1998). Included in this framework was a call for an increase in sampling effort as well as for the gathering and dissemination of historical records to better understand the current status of mussel populations. However, the call did not mention the potential of paleozoological data sets for examination of the long-term history of unionids. The potential value of such data is unprecedented because historic and modern data sets are often limited to some degree or biased temporally and spatially. It is therefore questionable whether modern data sets provide adequate baselines from which to infer biogeographic distributions and to measure species declines for the purposes of conservation and restoration. This is not to say that modern and historic accounts are not important but rather that they are insufficient to determine the long-term ecological processes responsible for mussel distributions (Humphries and Winemiller 2009; Randklev, Wolverton, et al. 2010; chapter 3, this volume).

Given that conservation efforts tend to be driven by recent, and often limited, historical accounts, the extent or magnitude of the decline of poorly known species such as unionids may not be fully recognized by

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conservation biologists. As a result, the status of a given mussel species may be far worse than is recognized, regardless of whether that species is considered to be rare or common (Régnier et al. 2009). Mussel conservation efforts would benefit from information concerning the long-term history of unionids because of the high stakes involved in conservation, such as local extirpation. Paleozoological data sets could provide insight on (1) the distributions of threatened species prior to large-scale impacts (e.g., impoundments) and the degree to which their ranges have changed; (2) the ecological characteristics of those species that have experienced the greatest declines; and (3) locations of prehistoric hot spots for what are today threatened species, and whether or not these locations have been recently sampled. In this chapter, we discuss zooarchaeological data that pertain to several unionid species recently listed for protection, thereby providing information that should inform ongoing conservation efforts.

## Background

The upper Trinity River drainage is located in north central Texas and is characterized by a humid subtropical climate that is also continental and therefore subject to wide fluctuations in temperature and precipitation (Neck 1990). The major river systems in this drainage (figure 4.1) are the Clear, West, Elm, and East Forks of the Trinity River (Huser 2000). All of these watercourses are now impounded for flood control and for commercial and residential purposes (Randklev, Lundeen, et al. 2010). In general, most of the upper Trinity River drainage is heavily urbanized, which has resulted in groundwater depletion (Garrett 1972). As a result, instream flow is typically low but can rapidly fluctuate as a consequence of surface runoff following heavy local rainfall or impoundment release. Combined with these effects is the discharge of environmental contaminants from both point sources (i.e., wastewater treatment plants) and nonpoint sources (i.e., runoff, septic tanks, and illegal dumping), which has impacted not only the biota within the upper Trinity, but also how the river is managed and used (Coogan et al. 2007; Coogan and LaPoint 2008; Ward et al. 2001, 2002).

The Trinity River mussel fauna is typical of those from the West Gulf Province, which includes rivers that drain to the south and west of the Mississippi drainage (Howells et al. 1996; Neck 1982b, 1990). However, very little is known about the distribution or abundance of mussel species in the upper Trinity River drainage (Neck 1990). The few historical records that exist are from the Elm Fork, from the Trinity River at the confluence of its forks near Dallas (Flook and Ubelaker 1972; Neck 1990;



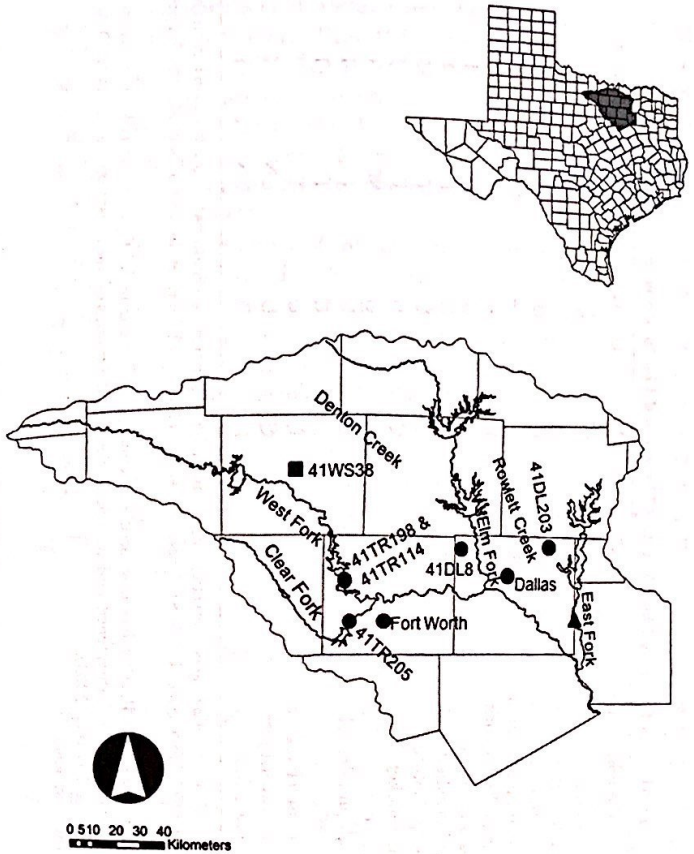


FIGURE 4.1. The Trinity River: black dots indicate locations of archaeological sites on the West (41TR114 and 41TR198) and Clear Forks (41TR205), Denton Creek (41DL8), and Rowlett Creek (41DL203). Black triangle indicates modern records for *Fusconaia* cf. *flava* (Randklev and Lundeen unpublished data). The black square denotes a single valve of *Pleurobema riddellii* collected from an archaeological site (41WS38) in the upper West Fork drainage.

Read 1954; Read and Oliver 1953; Singley 1893; Strecker 1931), and from the Clear and West Forks near Fort Worth (Mauldin 1972); these records include data on reservoirs associated with the drainages. Modern accounts have focused on both reservoirs and rivers (Howells 2006). Historical records indicate that two species now considered to be threatened (table 4.1) occurred in this drainage: *Potamilus amphichaenus* and *Pleu-*

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TABLE 4.1. Summary of Status Listings of 15 Mussels Recently Placed on the Threatened List in Texas

| *Species* | *Common Name* | *IUCN* | *NS* | *USFWS* | *AFS* | *TPWD* |
|---|---|---|---|---|---|---|
| *Fusconaia askewi* | Texas pigtoe | LR/NT | I | — | SC | T |
| *Fusconaia lananensis* | Triangle pigtoe | LR/NT | CI | U | SC | T |
| *Lampsilis bracteata* | Texas fatmucket | LR/NT | CI | U | SC | T |
| *Lampsilis satura* | Sandbank pocketbook | LR/NT | I | — | SC | T |
| *Obovaria jacksoniana* | Southern hickorynut | LR/NT | I | — | SC | T |
| *Pleurobema riddellii** | Louisiana pigtoe | LR/NT | CI | U | SC | T |
| *Popenaias popeii* | Texas hornshell | CR | CI | C | T | T |
| *Potamilus amphichaenus** | Texas heelsplitter | EN | CI | U | T | T |
| *Potamilus metnecktayi* | Salina mucket | — | CI | U | T | T |
| *Quadrula aurea* | Golden orb | — | CI | U | SC | T |
| *Quadrula houstonensis* | Smooth pimpleback | LR/NT | I | U | T | T |
| *Quadrula mitchelli* | False spike | CR | PE | U | T | T |
| *Quadrula petrina* | Texas pimpleback | — | I | U | T | T |
| *Truncilla cognate* | Mexican fawnsfoot | NR | CI | U | EN | T |
| *Truncilla macrodon* | Texas fawnsfoot | — | I | U | EN | T |

The conservation status of each species is designated by the following conservation, state, and federal agencies: International Union for Conservation of Nature (IUCN); NatureServe (NS); US Fish and Wildlife Service (USFWS); American Fisheries Society (AFS; given by Williams et al. 1993); and Texas Parks and Wildlife (TPWD).

Abbreviations: C, candidate for listing; CI, critically imperiled; CR, critically endangered; EN, endangered; I, imperiled; LR/NT, lower risk/near threatened; NR, not ranked; PE, possibly extinct; SC, special concern; T, threatened; and U, under review. For definitions of status listings see IUCN (2001), NS (2009), USFWS (2009), Williams et al. (1993), and TPWD (2003).

*Mussel species reported in the upper Trinity River drainage.





*robema riddellii* (Howells et al. 1996). *Lampsilis satura* (Neck 1990; Read 1954), *Quadrula houstonensis* (Read 1954; Strecker 1931), and *Truncilla macrodon* (Strecker 1931) have also been reported from this area, but more recent studies have dismissed these accounts as misidentifications (Howells 2000, 2002; Neck 1990; Randklev, Wolverton, et al. 2010). Of the 15 threatened species, only *P. amphichaenus* has been collected in recent years in the upper Trinity (Howells et al. 1996; Howells 2000; Neck and Howells 1994).

Given the limited number of mussel surveys conducted in the upper Trinity River drainage, the distribution and, more importantly, the status of each of the 15 species recently listed as threatened is poorly known. Therefore, the resolution of modern or historic accounts as benchmarks for assessing species distributions and measuring species declines is limited. Fortunately, zooarchaeological data are available that allow an examination of unionid biogeography prior to historical and modern impacts in this drainage. Thus, our goal is to examine the paleozoological evidence to determine if threatened mussels were found in the upper Trinity so that their range decline can be more comprehensively measured. This will allow us to determine if all 15 listed species are indeed threatened or are simply maintaining preindustrial impact distributions.

## Materials and Methods

To document the biogeography of threatened mussels prior to modern human impacts, we analyzed faunal remains from five archaeological sites dating between 2500 and 600 years before the present (Randklev and Wolverton 2009; Wolverton et al. 2010). Zooarchaeological collections were selected based on their availability and on the presence of unionid remains. Archaeological sites were located near the Clear Fork (official State of Texas archaeological site number 41TR205) and West Fork (41TR114 and 41TR198) of the Trinity River, as well as on Denton Creek (41DL8, Elm Fork) and Rowlett Creek (41DL203, East Fork) in north Texas (figure 4.1); with the exception of the last two, all rivers are now impounded. For each zooarchaeological shell fauna, species identifications were made using freshwater mussel guides (Howells et al. 1996; Parmalee and Bogan 1998) and through comparison to reference specimens in the Joseph Britton Freshwater Mussel Collection housed at the University of North Texas. Identified unionids were counted using two quantitative units: the number of specimens (NSP, both taxomically identified and unidentified umbos) and the number of nonrepetitive elements (NRE, number of identified umbos; Giovas 2009; Mason et al. 1998).

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The absolute abundances of unionids that existed in the upper Trinity River drainage during the late Holocene will never be known, because archaeological assemblages are often modified to some degree by cultural harvesting preferences, differential preservation, and differences in recovery techniques (Peacock 2000). Further, the absence of a particular species from an archaeological site is not necessarily evidence that it was not present at that site (Lyman 2008a). Shell properties such as shape and density affect how well the shell is preserved and therefore whether it can be identified (Kosnik et al. 2009; Wolverton et al. 2010). In highly fragmented assemblages, taxa with spherical and/or dense shells occur more often and are therefore proportionally more abundant. In these cases, species representation may be the result of postdepositional preservation factors rather than a reflection of the late Holocene aquatic environment.

To evaluate whether or not differential preservation influenced taxonomic abundance in shell assemblages, we calculated the proportion of taxonomically identifiable umbos from each archaeological site (see Peacock and Chapman 2001; Wolverton et al. 2010, for further details). Based on the presumption that fragmentation influences identifiability, we calculated the ratio of NRE to NSP; the higher the value of this ratio, the larger the number of identifiable umbos and the less fragmented and better preserved the assemblage (Lyman 1994; Peacock and Chapman 2001; Wolverton 2002).

Taxa may be underrepresented or absent in an assemblage not only because of poor preservation, but because of lack of recovery. The probability of recovering a given taxon is determined in part by its abundance in the sampled community. Therefore, taxa that tend to be rare on the landscape are typically absent from shell assemblages with small sample sizes, all else being equal (Lyman 2008a). To assess possible recovery bias, we graphed the total number of identified specimens (left and right valves combined) against the number of threatened taxa ($NTAXA_{threatened}$) for all five archaeological sites (see Lyman 2008a; 2008b:149–152, for further details). If threatened taxa are rare in, or absent from, small assemblages but present or abundant in large assemblages, then their absence from or rarity in drainages with small assemblages may be an artifact of archaeological sampling rather than a measure of their occurrence in a drainage.

## Results

Nineteen unionid species were identified in the five zooarchaeological assemblages (table 4.2). Of the taxa considered to be threatened in Texas



(table 4.1), shells of *Lampsilis* cf. *satura* were recovered only from 41TR198 on the West Fork of the Trinity River near Forth Worth, which is outside of its modern range (figure 4.2A). *Pleurobema riddellii* was collected at archaeological sites on the Clear and West Forks of the Trinity River and on Denton and Rowlett Creeks, suggesting a ubiquitous distribution over the last 2500 years (figure 4.2B). Zooarchaeological specimens of *P. riddellii* in the Clear and West Forks of the Trinity River (41TR198, 41TR205, and 41WS38) are outside its current distribution (figures 4.1 and 4.2B). *Potamilus amphichaenus* is absent from all shell assemblages in the upper Trinity River drainage, which is puzzling given its historical and modern occurrence there. However, sample size effects and postdepositional destruction of shells may explain the absence of this species (see below). *Fusconaia* cf. *flava* occurs at all five archaeological sites, which are within the modern range of this species (figure 4.2C). This species is not listed for protection because of uncertainties regarding its taxonomic status. However, it has been suggested that if ongoing genetic studies confirm its taxonomic validity, it should be listed as threatened (Howells 2009), and for this reason we have included it in our discussion.

Shape and density mediate fragmentation and therefore whether a unionid shell (or fragment thereof) can be identified taxonomically. Species with shells that are rectangular in outline and low in density are less likely to be preserved compared to species with shells that are spherical and relatively dense (Wolverton et al. 2010). Shells of *P. amphichaenus* are thin as well as elongated and are therefore prone to fragmentation. As a result, it is unlikely that remains of this species would survive; its presence in the upper Trinity River drainage during the late Holocene cannot be ruled out. Shells of *Lampsilis satura* are thin but more spherical in shape, which increases the likelihood that they will be preserved. However, this species only occurred at one site (41TR198), which also had the largest number of identifiable valves. This suggests that its presence is a function of sample size (see below). *Fusconaia* cf. *flava* and *P. riddellii* are dense and spherical in shape and thus their remains are more likely to be preserved. Both species are present in a number of shell assemblages in the upper Trinity River drainage. However, *P. riddellii* was absent from 41TR114 (West Fork of the Trinity River), which had the lowest number of identifiable valves. Thus, its absence there is probably the result of sampling error.

The probability of discovery of a taxon, assuming it occurred in the region in the past, should increase with larger sample size and/or better preservation (Lyman 2008a; Wolff 1975). Figure 4.3A emphasizes this point for shell assemblages in the upper Trinity drainage; as sample size (log NRE) increases, so does the $NTAXA_{threatened}$ in an assemblage. For

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TABLE 4.2. Taxonomic List, Relative Abundance, and Number of Unionids (NRE) Recovered from Archaeological Sites Located in the Upper Trinity River Drainage

| | 41DL8 | | 41TR114 | | 41TR198 | | 41TR205 | | 41DL203 | |
|---|---|---|---|---|---|---|---|---|---|---|
| *Species* | *No.* | *%* | *No.* | *%* | *No.* | *%* | *No.* | *%* | *No.* | *%* |
| *Amblema plicata* | 31 | 29.8 | 10 | 14.7 | 253 | 8.7 | 38 | 17.9 | 80 | 41.9 |
| *Arcidens confragosus* | — | — | — | — | 2 | 0.1 | — | — | — | — |
| *Fusconaia* cf. *flava* | 9 | 8.7 | 25 | 36.8 | 1394 | 47.8 | 4 | 1.9 | 4 | 2.1 |
| *Lampsilis* sp. | 2 | 1.9 | 3 | 4.4 | 6 | 0.2 | 58 | 27.4 | 8 | 4.2 |
| *Lampsilis hydiana* | 8 | 7.7 | 1 | 1.5 | 61 | 2.1 | 4 | 1.9 | 6 | 3.1 |
| *Lampsilis* cf. *satura* | — | — | — | — | 9 | 0.3 | — | — | — | — |
| *Lampsilis teres* | — | — | 1 | 1.5 | 34 | 1.2 | 4 | 1.9 | 22 | 11.5 |
| *Leptodea* sp. | — | — | — | — | 5 | 0.2 | — | — | — | — |
| *Ligumia* sp. | — | — | — | — | 1 | 0.0 | 31 | 14.6 | — | — |
| *Ligumia* cf. *subrostrata* | 1 | 1.0 | — | — | 3 | 0.1 | 19 | 9.0 | — | — |
| *Obliquaria reflexa* | 2 | 1.9 | — | — | 27 | 0.9 | — | — | — | — |
| *Plectomerus* sp. | 1 | 1.0 | 5 | 7.4 | — | — | 7 | 3.3 | — | — |
| *Plectomerus dombeyanus* | 11 | 10.6 | 9 | 13.2 | 417 | 14.3 | 19 | 9.0 | 8 | 4.2 |
| *Pleurobema* sp. | — | — | — | — | 3 | 0.1 | 2 | 0.9 | — | — |
| *Pleurobema riddellii* | 2 | 1.9 | — | — | 259 | 8.9 | 1 | 0.5 | 3 | 1.6 |
| *Potamilus* sp. | 2 | 1.9 | — | — | 8 | 0.3 | — | — | — | — |
| *Potamilus purpuratus* | 2 | 1.9 | 2 | 2.9 | 5 | 0.2 | 1 | 0.5 | — | — |
| *Quadrula* sp. | 6 | 5.8 | 4 | 5.9 | — | — | 1 | 0.5 | — | — |
| *Quadrula apiculata* | 1 | 1.0 | — | — | 5 | 0.2 | — | — | — | — |
| *Quadrula mortoni* | 14 | 13.5 | — | — | 224 | 7.7 | 2 | 0.9 | — | — |
| *Quadrula nobilis* | 1 | 1.0 | — | — | 2 | 0.1 | — | — | — | — |
| *Quadrula verrucosa* | — | — | 8 | 11.8 | 117 | 4.0 | 9 | 4.2 | 2 | 1.0 |
| *Toxolasma* sp. | — | — | — | — | — | — | 6 | 2.8 | 1 | 0.5 |
| *Toxolasma texasiensis* | 3 | 2.9 | — | — | 2 | 0.1 | 1 | 0.5 | 2 | 1.0 |
| *Truncilla* sp. | 2 | 1.9 | — | — | — | — | — | — | — | — |
| *Truncilla* cf. *donaciformis* | — | — | — | — | 2 | 0.1 | — | — | — | — |
| *Truncilla truncata* | 3 | 2.9 | — | — | 76 | 2.6 | 2 | 0.9 | — | — |
| *Uniomerus tetralasmus* | 3 | 2.9 | — | — | — | — | 3 | 1.4 | 55 | 28.8 |
| Total (NRE) | 104 | | 68 | | 2915 | | 212 | | 191 | |
| Unidentifiable umbos | 112 | | 209 | | 4380 | | 272 | | 1145 | |
| Total assemblage (NSP) | 216 | | 277 | | 7295 | | 484 | | 1336 | |
| % NRE to NSP | 48.1 | | 24.5 | | 40.0 | | 43.8 | | 14.3 | |

Sites distributed as follows: Denton Creek, 41DL8; West Fork, 41TR114 and 41TR198; Clear Fork, 41TR205; Rowlett Creek, 41DL203.
NRE, nonrepetitive elements; NSP, number of specimens.



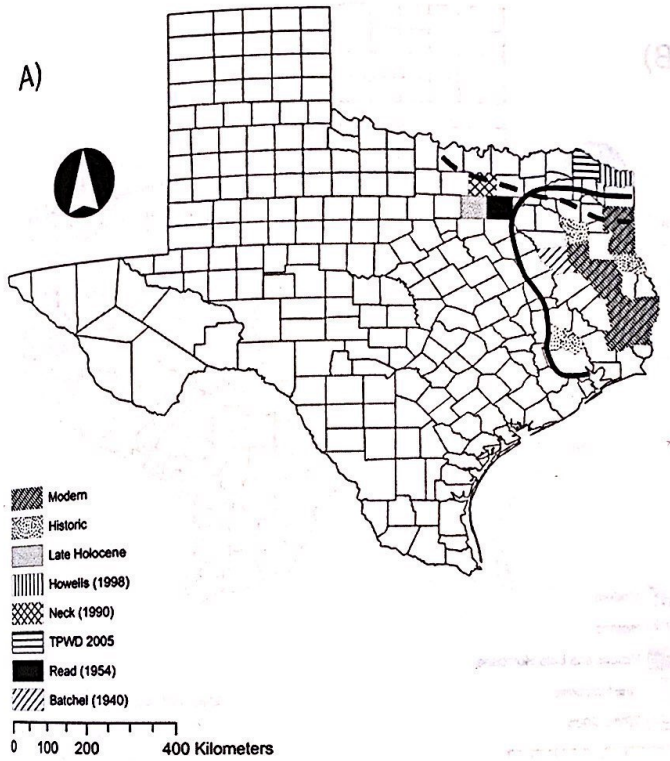


FIGURE 4.2. General historical and modern distributions for (A) *Lampsilis satura*; (B) *Pleurobema riddellii*; and (C) *Fusconaia flava*. The solid black line for all three maps is taken from Howells et al. (1996) and indicates the western boundary of historically known or potential ranges. Dashed lines indicate the boundary of ranges for *Lampsilis cardium* (A) and *Fusconaia askewi* (C). Historical records are from published accounts dating between 1892 and 1991; modern records are from published and unpublished accounts dating between 1992 and the present; prehistoric records date between 2500 and 600 years before the present.

example, *Lampsilis* cf. *satura* only occurs at site 41TR198, which produced the largest number of identified valves (table 4.2). This suggests that if each assemblage had sample sizes similar to that of 41TR198, it is likely that they would have produced more shells of the threatened species. Therefore, the presence of *Lampsilis* cf. *satura* at sites with small sample sizes cannot be ruled out. Similarly, the absence of *P. amphichae-*

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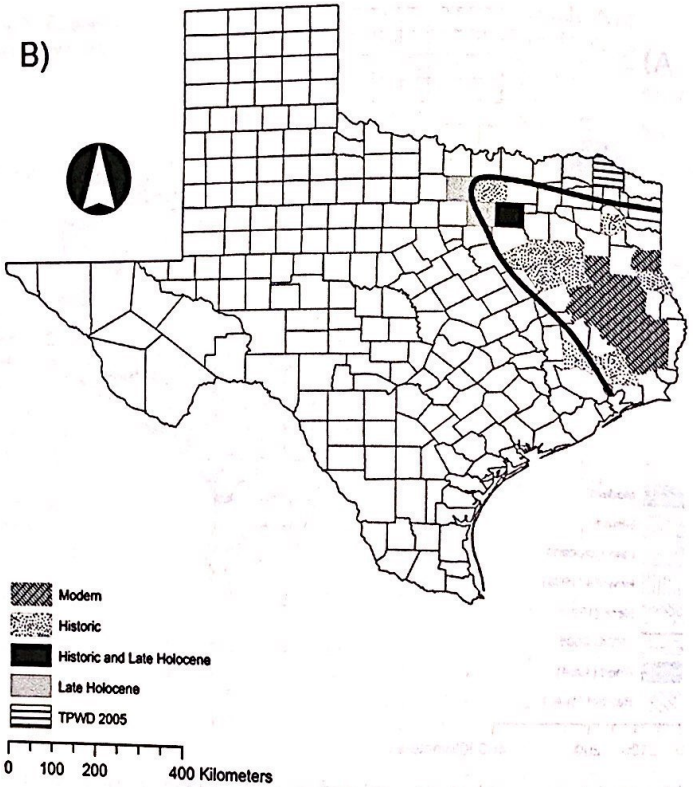


FIGURE 4.2. *Continued.*

*nus* from 41TR198 and its presence in historical and modern accounts suggests that larger zooarchaeological samples may reveal that it inhabited the upper Trinity River drainage during the late Holocene.

The intensity of fragmentation of shells in a particular assemblage may also explain the analytical absence of a species. To determine whether or not this is the case with the threatened species, we graphed the relationship between percentage NRE:NSP and the richness of threatened taxa for each archaeological site. Figure 4.3B suggests that, in general, a higher number of threatened species are identified when shells are less fragmented, but this relationship is statistically insignificant and weak. However, fragmentation exacerbates the influence of sample size on measures of NTAXA when assemblages are small. As a result, the absence of



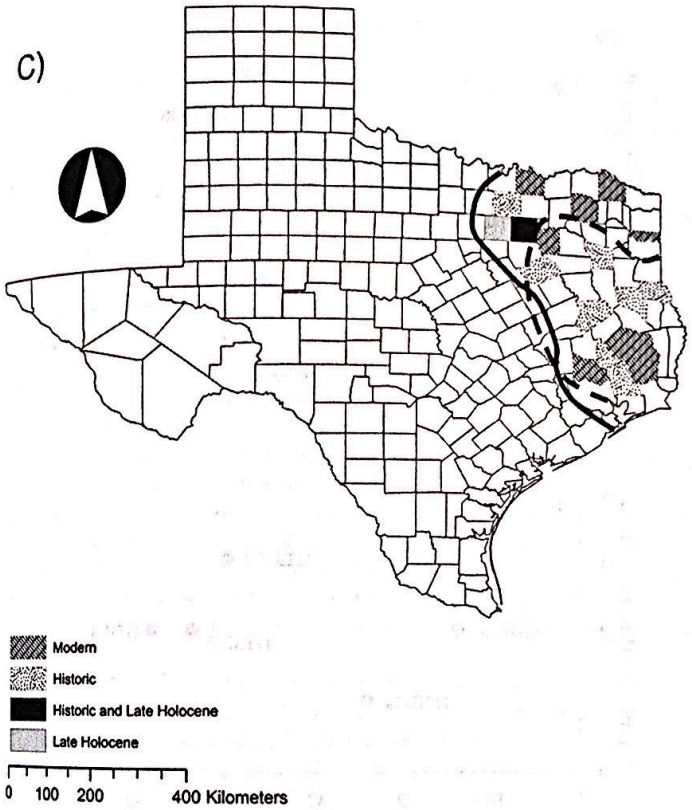


FIGURE 4.2. *Continued.*

threatened species from shell assemblages with small sample sizes and high fragmentation rates is likely not evidence of their absence from the upper Trinity River drainage during the late Holocene.

In summary, the valves of threatened species that were present and abundant in the upper Trinity River drainage are spherical and/or dense, which indicates differential preservation according to interspecific variability in shell robustness. For threatened species that are thin shelled, presence in the upper Trinity River appears to be a function of sample size. Small sample size and differential preservation may have reduced or eradicated the occurrence of threatened species in shell assemblages for this drainage. Thus, the late Holocene presence of *P. amphichaenus* and *Lampsilis* cf. *satura* within the upper Trinity River cannot be ruled out.

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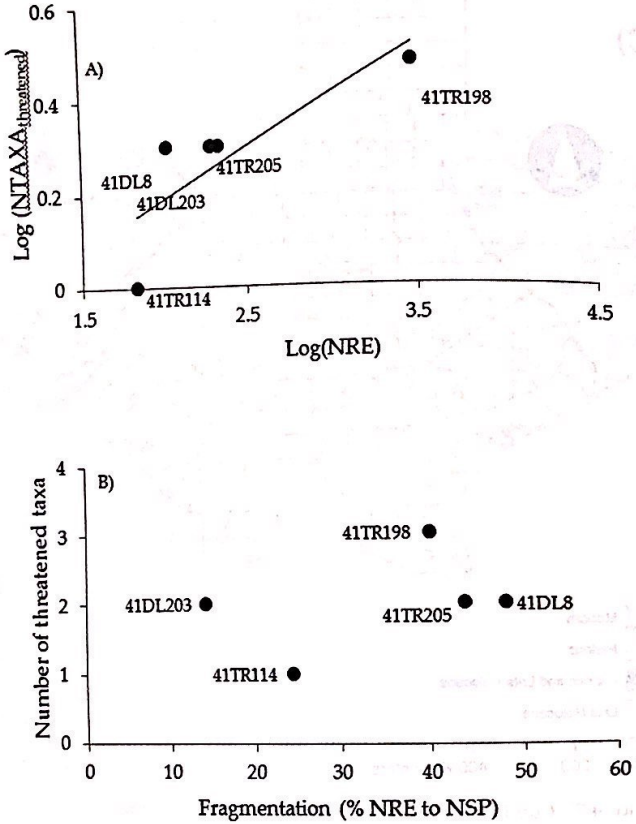


FIGURE 4.3. (A) Relationship between total unionid NRE (sample size) and $NTAXA_{threatened}$ of *Fusconaia* sp., *Lampsilis satura*, and *Pleurobema riddellii* for five archaeological sites in the upper Trinity River basin. The simple best-fit line is shown for reference ($r^2 = 0.66$, $p < 0.05$). (B) Insignificant, weak relationship between percentage NRE:NSP and the occurrence of threatened taxa for five archaeological sites in the upper Trinity River basin ($\rho = 0.23$, $p = 0.72$). Archaeological sites are 41TR205 (Clear Fork), 41DL8 (Denton Creek), 41DL203 (Rowlett Creek), 41TR114 (West Fork), and 41TR198 (West Fork).



## Discussion

The late Holocene zoogeography of mussels in the upper Trinity is important for management and ecology at the regional and local scales. *Lampsilis satura* is only known to occur in rivers east of the Trinity River drainage (Howells et al. 1997). Accounts of this species in the upper (Neck 1990; Read 1954) and lower Trinity River (Batchel 1940) exist, but they have been dismissed as misidentifications (Howells 2000, 2002). *Lampsilis* cf. *satura* was found at 41TR198, located near the West Fork of the Trinity River. Specimens from this site had a hinge line that forms an S shape that is characteristic of *L. satura*, but their umbos were less elevated, which is atypical for this species (Robert G. Howells, personal communication, 2009). This morphological abnormality is important because *Lampsilis cardium*, a closely related species, is found nearby in the Red River drainage (dashed line in figure 4.2A). *Lampsilis cardium* is morphologically similar to *L. satura*, and genetic studies have failed to demonstrate differences between the two (Howells 2009). Umbos of *L. cardium* can range from full and high to low and small, and individuals from site 41TR98 resemble the latter. However, the hinge line for *L. cardium* is J shaped rather than S shaped (Howells et al. 1996). Therefore, the individuals collected from site 41TR198 may represent a morphologically distinct population of *L. satura* that inhabited the upper Trinity River drainage.

Historically, *P. riddellii* ranged from the Trinity River east into Louisiana (Howells et al. 1996, 1997; Vidrine 1993). This species was recorded during the late 1800s and early 1900s in the Elm Fork of the Trinity and in the main course of the Trinity River near Dallas (Singley 1893; Strecker 1931) and is now considered to have been extirpated from these watercourses because of habitat degradation (Read and Oliver 1953; Strecker 1931). Modern surveys have failed to record this species in this drainage (Howells 2009; Howells et al. 1997). The limited historical sampling effort in the Trinity drainage makes it difficult to infer the distribution of this species prior to wide-scale human impacts (Randklev, Lundeen, et al. 2010). In spite of the paucity of historical records, range maps for *P. riddellii* have excluded large portions of this drainage (figures 4.1 and 4.2B). Paleozoological data indicate that this species inhabited the Clear and West Forks of the Trinity River, outside of its current range. This species also occurred in the Elm Fork (41DL8) and East Fork (41DL203) drainages, indicating that it was widely distributed in the upper Trinity River drainage during the late Holocene. However, the low relative abundance of this species in the studied assemblages suggests that it may have been rare, since shells of *P. riddellii* are dense and spherical in shape and thus should be resistant to fragmentation. The presence of this species in as-

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semblages with varying preservation histories underscores this point. Given the observed paleozoological distribution of *P. riddellii*, it is likely that changes brought about by an increase in the modern human population eliminated late Holocene populations.

Data from shell assemblages in the upper Trinity River drainage indicate that *Fusconaia flava* was abundant during the late Holocene. This species has the highest proportional abundance of any species in archaeological sites near the Clear and West Forks of the Trinity River. For shell assemblages from sites on Denton and Rowlett Creeks, this species was less abundant, which suggests that instream habitat near these sites may have been marginal (table 4.2). Our reasoning is similar to the explanation provided for the low abundance of *P. riddellii* in these shell assemblages (see previous discussion). Historic accounts of *Fusconaia chunii*, later synonymized with *F. flava* (Howells et al. 1996), in the upper Trinity River drainage were reported in the Elm Fork (Strecker 1931) and in the main stream of the Trinity River near Dallas (Singley 1893; Strecker 1931). However, Vidrine (1993) hypothesized that these accounts may in fact have been records of *Fusconaia askewi*. These two species overlap in range (figure 4.2C) and have similar morphologies. However, individuals collected from shell assemblages in the upper Trinity River drainage do not resemble modern specimens of *F. askewi*. Rather, they compare well with individuals of *F. chunii* collected by J. A. Singley in the late 1800s from the Trinity River near Dallas (reference specimens housed at the Texas Natural Science Center, Non-vertebrate Paleontological Laboratory). Read (1954) reported observations of *Fusconaia undata* from Parsons Slough near Dallas, but this account is not listed in current taxonomic references (Howells et al. 1996). Recent studies have indicated that *F. undata* is an ecophenotype of *F. flava* and the species has therefore been synonymized with *F. flava* (Graf 1997). Modern surveys have reported live individuals of *Fusconaia* cf. *flava* from the East Fork of the Trinity River (figure 4.1) approximately 70 km (42 miles) from Dallas (Randklev and Lundeen, unpublished data). Given this record, as well as data from shell assemblages in the upper Trinity River and historic accounts, it is reasonable to assume that this species was present during the late Holocene and could still persist in this drainage.

## *Conservation Status*

Paleozoological occurrences of threatened unionid species throughout the upper Trinity River drainage suggest that the geographic range of these species was once more extensive than has been historically documented. Individuals resembling *Lampsilis satura* were found in the upper Trinity River drainage, indicating that this species had a much larger pre-



industrial range (figure 4.2A). This species now appears to be restricted to the Sabine, Neches, and Angeline Rivers of east Texas (Howells 2009; Karatayev and Burlakova 2007, 2008; Randklev, Kennedy, et al. 2010). Only a few live individuals have been collected in these drainages, which suggests that the species has become exceedingly rare. Paleozoological data also indicate that *P. riddellii* was more widely distributed in the past. This species was collected from shell assemblages near the Clear and West Forks of the Trinity River, outside its modern range (figure 4.2B). Today, this species is considered to have been extirpated from the upper Trinity River drainage (Howells 2009). Since the mid-1990s, live individuals of *P. riddellii* have only been collected from the Neches and Angelina Rivers (Howells 2009; Karatayev and Burlakova 2007, 2008), which underscores the range contraction of this species. For both *L. satura* and *P. riddellii*, no large populations are known to occur anywhere in Texas (Howells 2009). *Fusconaia* cf. *flava* was present and, in general, abundant at all five archaeological sites in the upper Trinity River drainage (table 4.2). Shell assemblages in the upper Trinity containing this species are within its modern range (figure 4.2C). Live individuals have been collected from a number of sampling localities in east Texas, including the East Fork of the Trinity River. However, confusion with other pigtoes in Texas and the taxonomic uncertainty of *Fusconaia* cf. *flava* make it difficult to establish its conservation status (Howells 1997, 2009).

In summary, comparisons between paleozoological data from the upper Trinity River drainage and historical and modern accounts throughout Texas indicate that both *L. satura* and *P. riddellii* have experienced severe range curtailment and appear to be in serious trouble. The status of *Fusconaia* cf. *flava* is less clear given its taxonomic uncertainty. Nevertheless, this species has not been collected in recent years in the Trinity River and its associated tributaries north of Dallas. The decline of these species and others listed by TPWD highlights the historical and continued degradation of freshwater ecosystems in Texas. For the upper Trinity River drainage, this situation is exacerbated by wide-scale urbanization that has likely reduced or eliminated sensitive biota.

## *Potential Reasons for Decline*

Landscape modifications stemming from unbridled human population growth are one of the main factors contributing to the decline of freshwater mussels throughout North America (Poole and Downing 2004). Other factors include impoundments, groundwater depletion, environmental contaminants, sedimentation, loss of host fishes, and the homogenization of freshwater fauna through nonnative introductions (Bogan 1993; Brim Box and Mossa 1999; Neves 1997; Rahel 2002). The upper Trinity River

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drainage provides a crossroads for many of these factors. Specific causes for the decline of mussel populations within the upper Trinity River have not been identified, though there are several factors that have likely influenced these populations.

Beginning in the early 1900s, impoundments were constructed on the East, Elm, West, and Clear Forks of the Trinity River to increase flood control, to provide drinking water, and to supply irrigation water (Gard 2009; Hodge 2005). The zoogeography of freshwater mussels is largely dependent on the distribution of their fish hosts because the dispersal of mussels is mediated by the movement of fishes bearing glochidia (Watters 1992, 1996). As a result, impoundments have contributed to mussel declines by impeding the longitudinal movement of host fishes. Impoundments also affect downstream mussel communities by altering the seasonality of flow, changing temperature regimes, influencing the deposition and movement of sediments and patterns of scour, and altering the organic materials available to mussels (Vaughn and Taylor 1999 and references therein). In our study area, the Clear, Elm, East, and West Forks of the Trinity River and Denton Creek were impounded within approximately 55 years (Randklev, Lundeen, et al. 2010). The short time frame makes it likely that unionid populations were acutely impacted.

Similarly, impoundments and groundwater depletion have caused water flow in many of the tributaries and sections of the upper Trinity River to become intermittent during warm summer months and periods of low rainfall. During these episodes, rapid changes in water depth may strand unionids, which causes high rates of mortality due to desiccation and increased predation by riparian vertebrates (Lundeen and Randklev, personal observations, 2009). Sections of the upper Trinity River drainage that remain perennial do so as a result of wastewater treatment plant discharge. Discharge of effluent is associated with risks; studies in the upper Trinity River drainage have demonstrated the deleterious effects of personal care products and pharmaceuticals on growth rates of aquatic biota (Coogan et al. 2007; Coogan and LaPoint 2008). Moreover, there is a growing body of literature that suggests these products may inhibit the recruitment, and therefore the long-term sustainability, of existing mussel populations (Cope et al. 2007).

In addition, the release of pesticides, herbicides, and industrial and human-related wastes has played a role in the degradation of the upper Trinity River drainage. The magnitude of these impacts is such that the US Public Health Service has described the upper Trinity River as "septic" (Gard 2009). Because these compounds are persistent at biologically relevant concentrations for long periods of time, there is currently a ban prohibiting the removal and consumption of fish from portions of the Clear and West Forks and the Trinity River below Dallas (Ward et al. 2001, 2002). For unionids, these toxins seem to have the greatest effects



on younger individuals, either causing immediate mortality or preventing the attachment of juvenile mussels to host fish (Howells et al. 1996 and references therein). These environmental contaminants may therefore affect the long-term viability of mussel populations, especially for potentially sensitive species such as those listed by TPWD. Unfortunately, the effects of urbanization on this drainage are not strictly a modern phenomenon. During the early 1890s, raw sewage was emptied directly into the Trinity River such that a reporter from the *Dallas Daily Times-Herald* wrote that "for ten miles down from Dallas, the river is in horrible condition. Its banks are strewn with filth, the surface of the water is covered with filth, the river is full of filth for miles, it is nothing less than a contaminating slough of filth" (October 3, 1891:p. 7). Unionids are some of the most pollution-sensitive species occurring in freshwater environments (Ortmann 1909; Van Hassel and Farris 2007). Thus, the effects of these environmental contaminants, combined with the intense urbanization of the upper Trinity River drainage, have undoubtedly impacted the mussel fauna and have likely played a role in the decline of mussel species that are now considered to be threatened.

Along similar lines, the absence of detailed historical accounts prior to modern impacts may also explain the disparity between prehistoric and modern/historical records. Early records for this drainage were gathered after impoundments were built and during periods of release of environmental contaminants into the upper Trinity River drainage, and it is unclear to what degree these records are the result of these impacts. More importantly, for species that are sensitive to environmental change it is unlikely that historical data accurately record distributions. A recent study of *Plectomerus dombeyanus* in this drainage using zooarchaeological data has demonstrated range curtailment, yet this species is considered tolerant of human impacts (Randklev, Wolverton, et al. 2010). While *P. dombeyanus* is not "threatened," the results of the study underscore two points: First, historical and to some degree modern sampling efforts for the upper Trinity River drainage have been insufficient; second, change in unionid distributions in this drainage appears to be related to modern human impacts. Unfortunately, for other rivers in Texas such changes have not been fully documented because data on the long-term history of mussels have been largely ignored.

## Management Implications

The unionids discussed here are among the most threatened in the state of Texas. Their future depends, at least partially, on knowledge of both their past and present distributions. Our results have two main implications for ongoing efforts to list these species under the ESA. First, it is

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well known that the periphery of a species range is often the area where organisms are most sensitive to environmental change. As a result, "species declines should be the most detectable at the edges of its range rather than in the center where these declines may be muted by high abundances of that species" (Lyman 2007:107 and references therein). For both *L. satura* and *P. riddellii* (figures 4.2A and 4.2B), the upper Trinity River drainage is one such area. Therefore, the magnitude of range contraction observed for both species revealed by comparing paleozoological data with modern and historic records is probably accurate. This suggests that things are worse for these species than has been realized. As a result, these species are good candidates for protection under the ESA.

Second, the discrepancies between historical and paleozoological records within the upper Trinity River drainage indicate that a number of areas still need to be sampled. In particular, zooarchaeological shell assemblages near the Clear and West Forks of the Trinity River and Denton Creek are taxonomically rich, suggesting that a more diverse mussel community existed in the past. Historical and modern sampling efforts in these drainages have been largely absent. Thus, relict populations of threatened species may still exist in these drainages. If so, these populations should be identified and included in ongoing conservation efforts. Thus, paleozoological data sets could help direct and focus future sampling efforts for these species. In sum, paleozoological research provides data sets that differ in important ways from historical records. As such, the former can corroborate and correct or contradict the latter, and thereby more validly inform conservation actions. On the basis of the geographically small study here, paleozoological data should be regularly consulted by those interested in the future well-being of unionid species.

## Acknowledgments

We thank James H. Kennedy, University of North Texas; Dave Britton, US Fish and Wildlife Service; Robert G. Howells, BioStudies; Lyubov Burlakova, Great Lakes Center; and Duane Peter, GeoMarine, Inc., for supporting various aspects of this research. Steve Wolverton and R. Lee Lyman offered constructive criticism and insightful comments on the manuscript.

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