# Status of Freshwater Mussels in Texas

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## Introduction

North America is the global epicenter of freshwater mussel diversity. Within North America, freshwater mussels are considered the most rapidly declining group of freshwater organisms. There are approximately 300 freshwater mussel species recognized in the United States. Of these, 53 species are known from Texas. Fifteen species of mussels maintain a state status of threatened in Texas; of which one is a candidate for federal protection and 11 others are currently petitioned for listing under the US Endangered Species Act (ESA). Relatively little is known about freshwater mussels in Texas and few studies have examined Texas freshwater mussels in detail. Most of what is known about freshwater mussel biology and conservation is drawn from other areas of the country. Herein, we summarize what is known about the historical distribution of Texas freshwater mussels based on material collected in Texas since 1829 and deposited in museums around the United States and Canada. We also provide a list of publications with particular relevance to Texas freshwater mussels, and a summary description of freshwater mussel biology and conservation threats combining results of studies across North America with our own studies of freshwaters in Texas.

## Database Summary

We requested records of Texas freshwater mussels (Unionidae) from 15 institutional biodiversity collections in the United States and Canada, all but two of which were outside of Texas. Results of these queries were standardized and collated into a Texas Freshwater Mussel Database (TFMD) consisting of 7442 records, dating from 1829 to 2005. Staff of the Institute of Renewable Natural Resources georeferenced all records based on verbatim locality data attached to each record. Precision of locality data varied from exact coordinates to generalized locations such as county or river basin, and georeferenced records were categorized accordingly. Taxonomies under which many of these records are being curated did not reflect current usage as compiled by Howells *et al*. (1996); therefore, synonyms were assigned according to that reference and the MUSSEL Project Simpson-Haas Index available online. Based on this revised taxonomy, our database comprises records of 51 unionid species currently recognized from Texas, and includes 877 records for 10 of the 11 species currently petitioned for

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listing as federally endangered or threatened (there are no records for the Salina mucket)(Fig. 1). Every major river basin in Texas with the exception of the Canadian and Red river basins has at least one record of a currently state threatened, federally petitioned, or federal candidate species. (Table 1)(Fig. 2). This latter subset of records dates from 1889 to 2005. The most common species in the database is the Threeridge, with 668 records, followed by the Pondhorn (596 records) and Tampico Pearlymussel (543 records) (Fig. 1).

Based on museum records to which appropriate collection data were attached, mussel collecting in Texas appeared to increase steadily until about 1970, and has declined from then to at least 2005 (Fig. 3). The single museum with the greatest number of Texas freshwater mussel records is the Baylor University Mayborn Museum Complex, with 3074 records (BU-MMC in Fig. 4). Other notable collections include the Ohio State Museum (OSM; 837 records), the United States National Museum (USNM; 832 records), and the University of Michigan Museum of Zoology (UMMZ; 712 records; Fig. 4). 163 Texas counties are represented in the TFMD (Fig. 5), with McLennan having more records than any other county (909), followed by Liberty (472) and Hardin Counties (268).

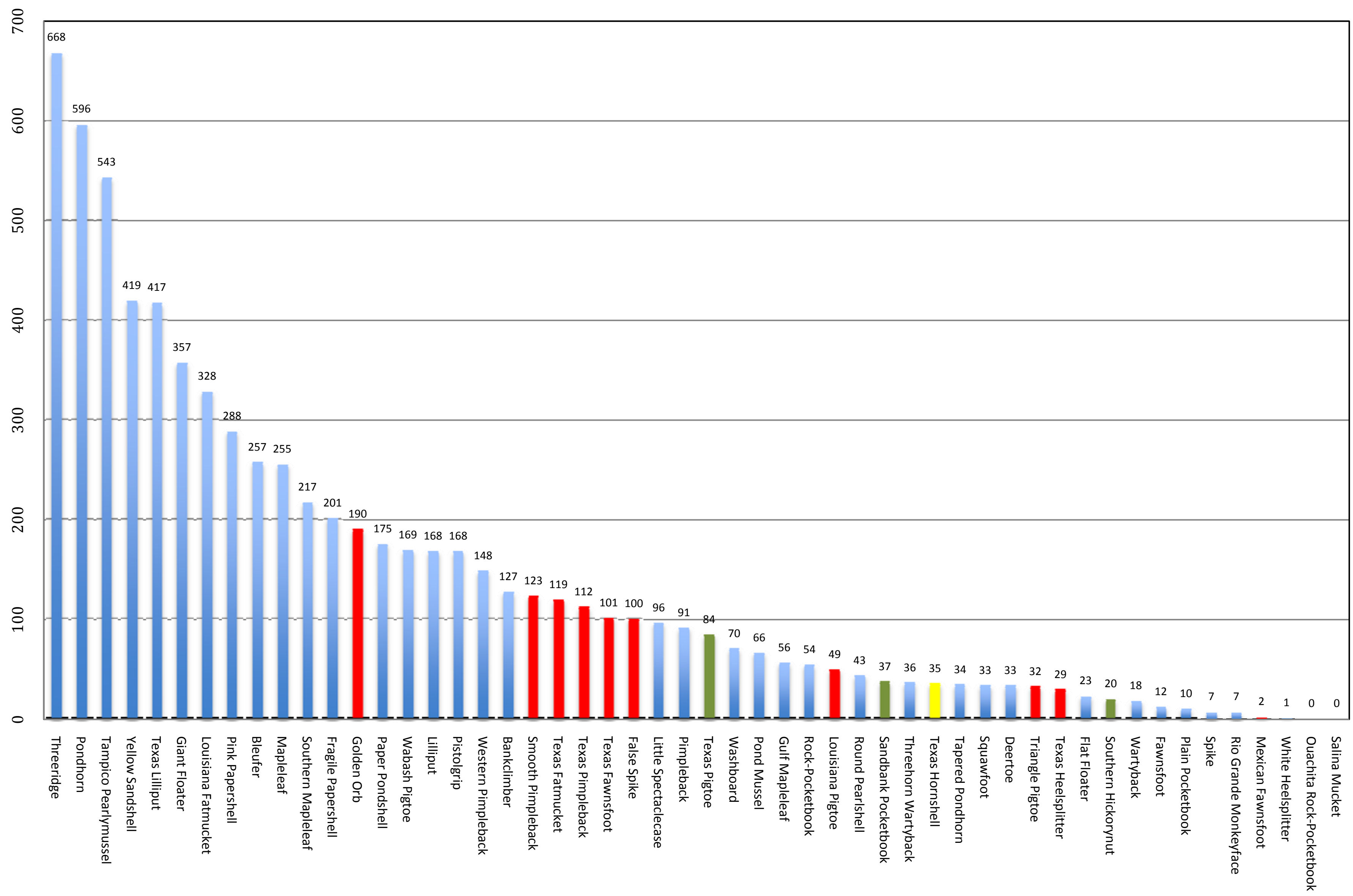


Figure 1. Freshwater mussel species included in the TFMD. Red indicates those species that have been petitioned for listing as threatened or endangered under the ESA. Green denotes state threatened species and those in yellow are candidates for federal protection under the ESA. Note: There are no records for the Salina mucket (a petitioned species).

River Basin

| | Listing Status | Brazos | San Bernard | Canadian | Colorado | Cypress | Guadalupe | Lavaca | Neches | Nueces | Red | Rio Grande | Sabine | San Antonio | San Jacinto | Sulphur | Trinity |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Texas pigtoe** | ST | 3 | | | | | 1 | | 33 | | | | 32 | 1 | 10 | | |
| **Triangle pigtoe** | ST, P | | | | | | | | 23 | | | | 4 | 1 | | | 4 |
| **Texas fatmucket** | ST, P | | | | 80 | | 28 | | 2 | 1 | | | 1 | 3 | | | |
| **Sandbank pocketbook** | ST | | | | 1 | | | | 14 | | | | 14 | | 7 | | 1 |
| **Southern hickorynut** | ST | 1 | | | | | | | 15 | | | | 4 | | | | |
| **Louisiana pigtoe** | ST, P | | | | | | | | 16 | | | | 4 | | 4 | | 25 |
| **Texas hornshell** | ST, C | | | | 2 | | | | | 1 | | 31 | | | | | |
| **Texas heelsplitter** | ST, P | 7 | | | | | | | 11 | | | | 3 | | | | 6 |
| **Salina mucket** | ST, P | | | | | | | | | | | | | | | | |
| **Golden orb** | ST, P | 45 | | | 29 | | 45 | 5 | 3 | 10 | | 1 | 1 | 38 | 1 | | 5 |
| **Smooth pimpleback** | ST, P | 28 | 1 | | 59 | 1 | | | 8 | 2 | | | | 1 | 1 | | 17 |
| **Texas pimpleback** | ST, P | | | | 79 | | 20 | | 1 | 4 | | | | 1 | | | 2 |
| **False spike** | ST, P | 16 | | | 42 | | 33 | 2 | | | | 1 | | | | 1 | 2 |
| **Mexican fawnsfoot** | ST, P | | | | | | | | | | | 2 | | | | | |
| **Texas fawnsfoot** | ST, P | 40 | | | 42 | | 6 | | 5 | | | | 3 | | | | 3 |

Table 1. Number of occurrences within major river basins in Texas of 15 freshwater mussel species listed as either state threatened, federal candidates for listing, or have been petitioned for listing under the Endangered Species Act. Data is derived from a compilation of museum collections and records. Listing status: ST=State threatened, P=petitioned for listing as threatened or endangered under the US Endangered Species Act, C=candidate for protection under the US Endangered Species Act

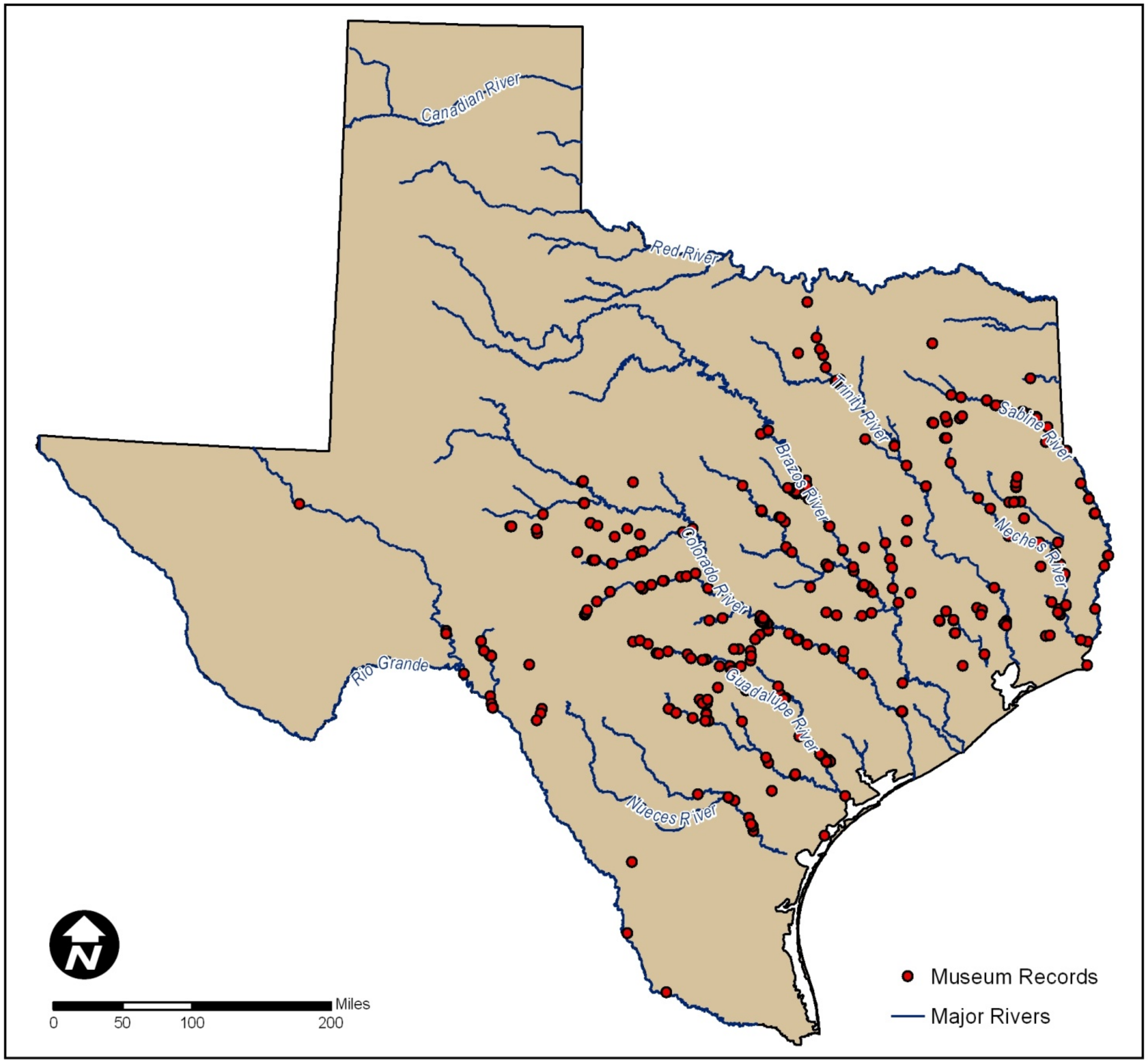


Figure 2. Locations of freshwater mussel species contained in the TFMD listed as state threatened, candidates for federal protection, or petitioned as threatened or endangered under the US Endangered Species Act.

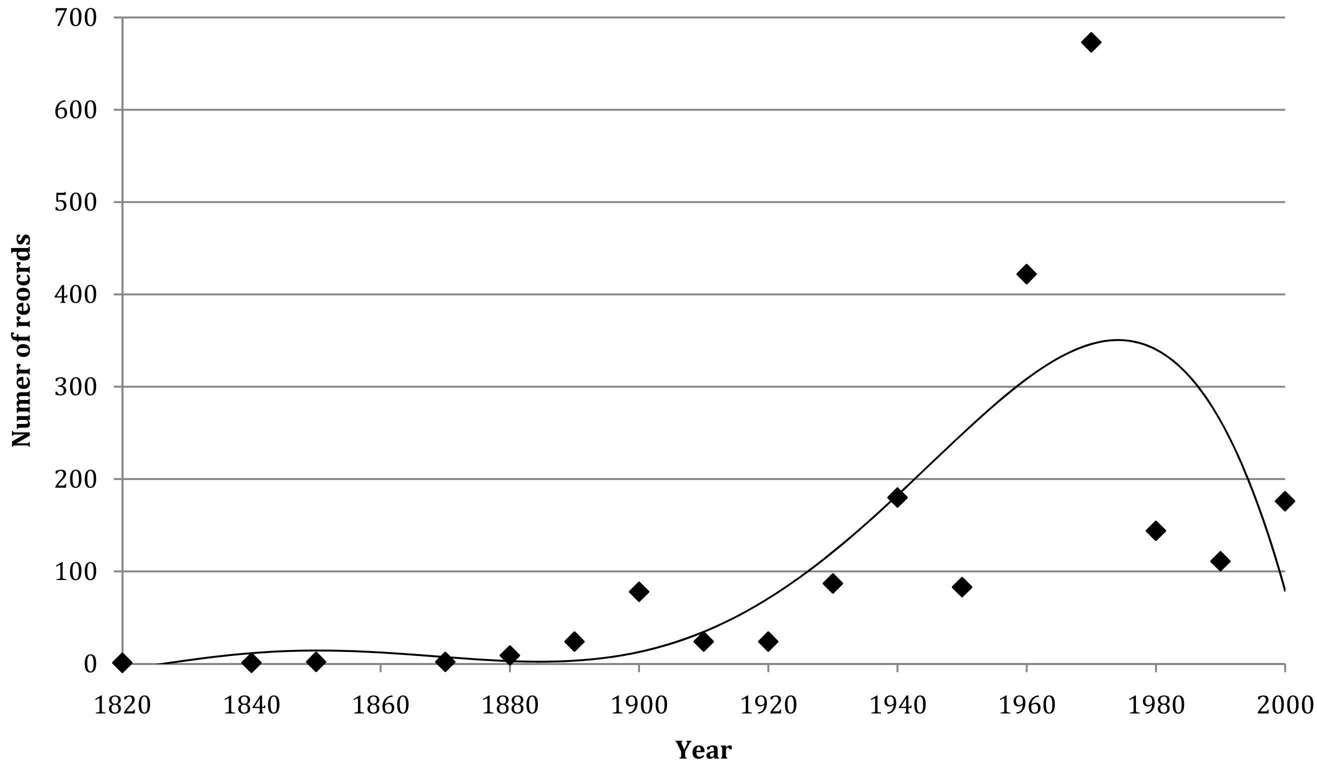


Figure. 3. Number of records entered into the TFMD in each decade from 1820 to 2005.

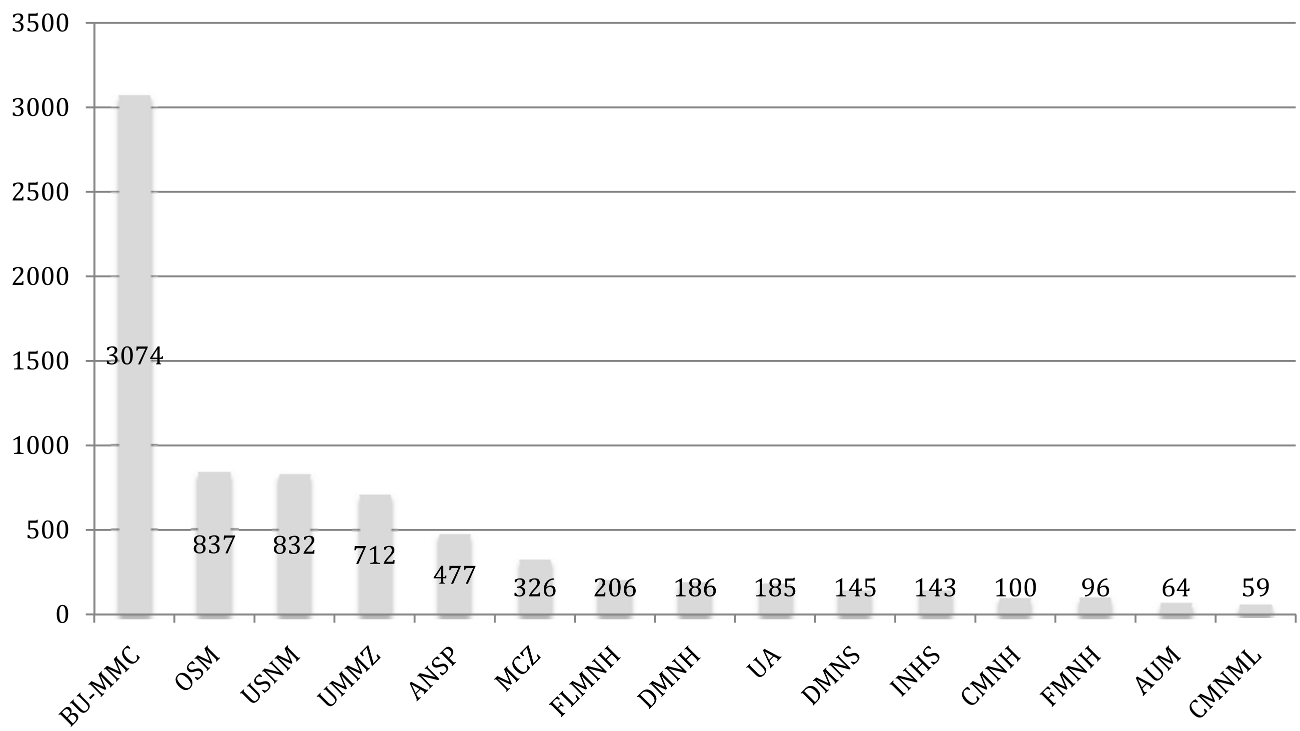


Figure. 4. Distribution of TFMD records by source institution. See Appendix D for an explanation of museum acronyms.

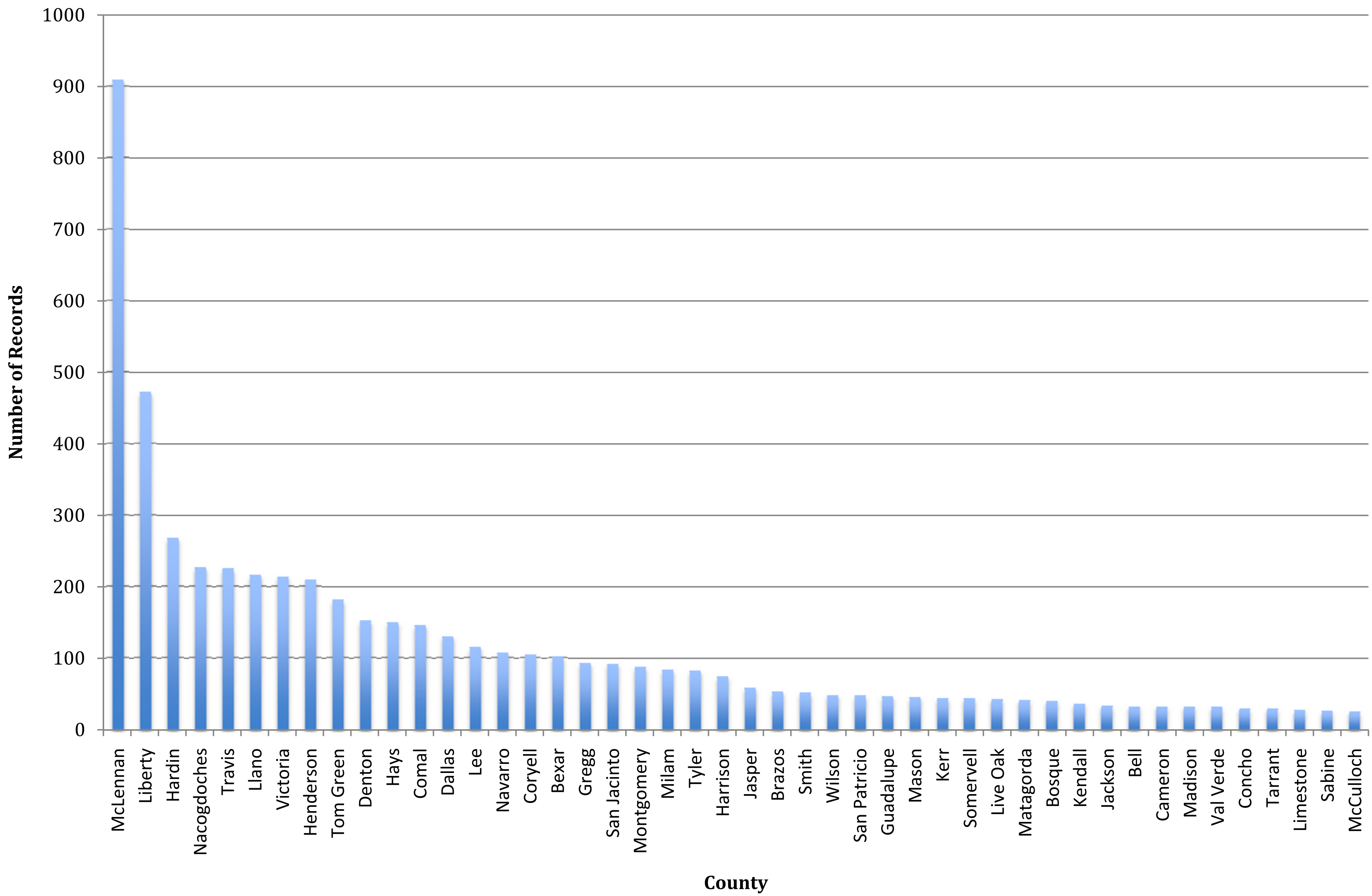


Figure 5. Location distribution by county of freshwater mussel species contained in the TFMD.

## Spatial Database

After the museum records were acquired and taxonomic names were standardized, a spatially explicit database was created by georeferencing the records using ESRI ArcGIS Arcmap 9.3. Various data layers were used for location reference including streams, rivers, and waterbodies from the National Hydrography Dataset, major roads, city boundaries from the Texas Strategic Mapping Program, urban areas from the Texas General Land Office, county boundaries, river basin boundaries from the U.S. Geological Survey, and National Agriculture Imagery Program 2004 imagery. Each record is represented by a point feature and is placed according to the locality description found in the museum record. Descriptions ranged from precise GPS coordinates to highly generalized locations (*e.g.*, county or river basin). Points were placed as accurately as possible based on the quality of their source data, and then assigned an accuracy rank, ranging from 1 (most accurate) to 10 (least accurate). An Internet search was performed for named locations not found in available data layers.

The accuracy scale developed is as follows:

1-precise coordinates (Lat./Long, UTM, or other)
2-Road/river intersection
3-x direction, x miles from x city or intersection
4-on x river within x city; on x river within x park
5-on x river within large city (i.e., Austin, Dallas, Houston, etc.); park
6-lake; city
7-creek or river within a county
8-county
9-creek or river
10-river basin

When a park, city, lake, county, creek/river, or river basin was the only location description provided, a point was placed within the bounds of that named feature. Accuracy ranks were adjusted for records from the general scale as needed. Notes were made in the database if the exact location description could not be used as stated. The final product is an

ESRI file geodatabase (.gdb) with spatial and attribute data of all museum records with locality information adequate for deriving a position.  An example of a map product derived from this geodatabase is in Figure 6.

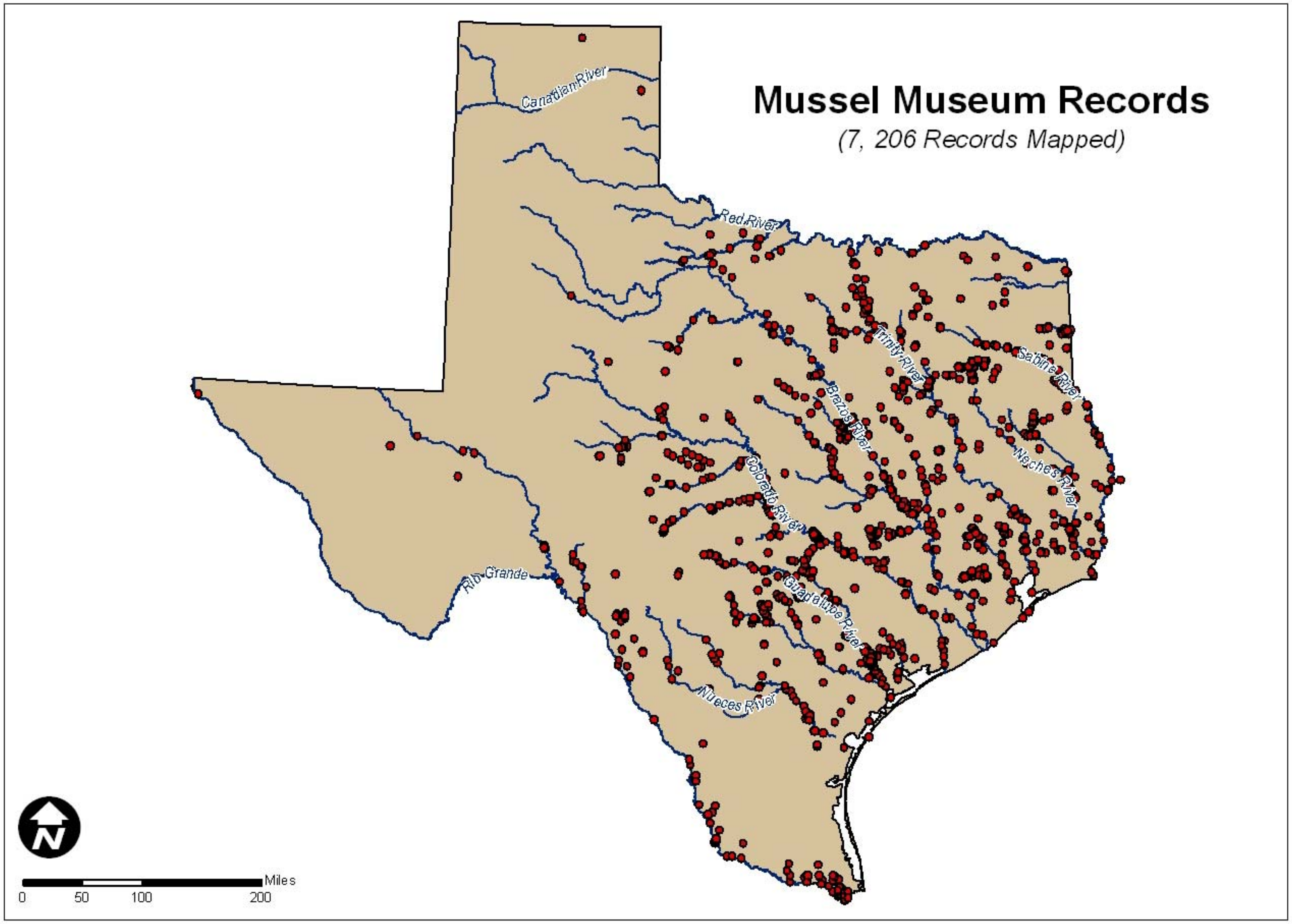


Figure 6. Locations of all freshwater mussel museum records with adequate locality information for mapping purposes.

# River Basins of Texas

Precipitation ranges from an average of 8 inches per year in far West Texas to as much as 60 inches per year in coastal east Texas (Fig. 7) (TPWD, TCEQ, and TWDB, 2003). Texas rivers reflect this precipitation variability: rivers in west Texas generally exhibit greater seasonality in flows and a higher frequency of flash floods, and rivers in east Texas generally carry higher flows with less seasonal variation. Many of the state's streams and rivers flow from the north and west toward the south and east (see Fig. 8). Texas, more than any other state in the United States, has a hydrological regime with a high flash-flood potential (Beard, 1975). This potential varies across the state from west to east, like the river drainage basins themselves, and is an important influence on the hydrology, hydraulics, and aquatic ecosystems in Texas rivers.

Rivers in Texas can be described in many ways based on the wide variety of conditions across the state. For descriptive purposes, the state of Texas and its river systems are coarsely categorized into five districts: East, North-Central, South-Central, Lower Rio Grande basin, and West. These districts are described briefly below in terms of geology, climate, hydrologic regime, and biota.

## *East Texas*

East Texas rivers (Lower Red, Lower Trinity, Lower Brazos, Navasota, Sabine, Neches) drain the portion of Texas with average rainfall between 30 and 50 inches a year. The region is dominated by flat landscapes and either clay-rich or sandy soils (the latter associated with the Sabine and Neches watersheds). Rivers of this region historically experienced periodic flood pulses that connected river channels to floodplains. Watersheds of the region are dominated by agriculture and forestland. The 1950s were a period of dam construction across this region, and today most major rivers have been impounded for flood control purposes. Water-based recreation is popular in this region, especially fishing in some of the state's largest and most productive reservoirs. The region contains several imperiled aquatic species, including paddlefish (*Polyodon spathula*) and sharpnose shiner (*Notropis oxyrhynchus*). Fish communities in east Texas (in basins like the Brazos River) are dominated by species adapted to high

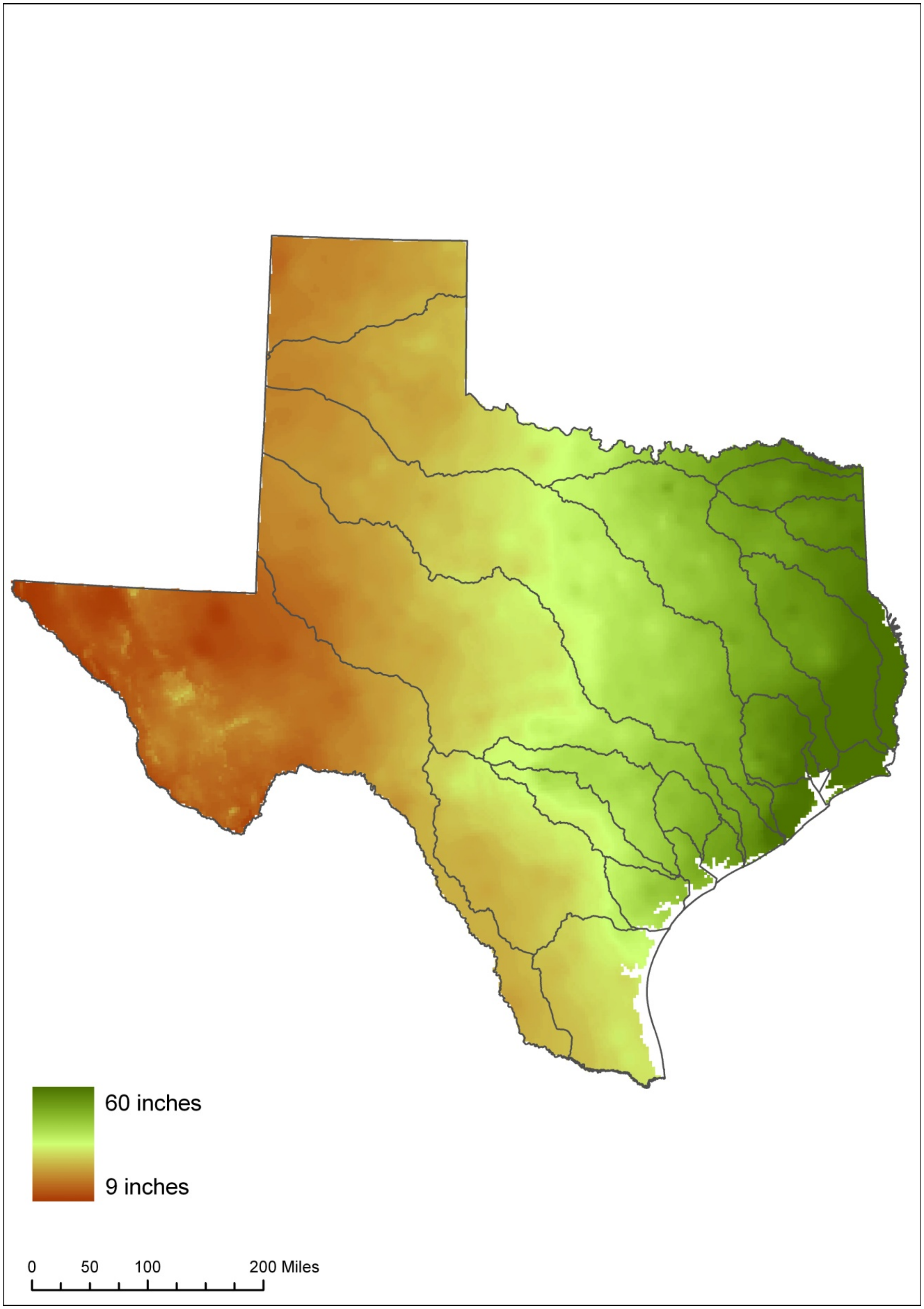


Figure 7. Texas precipitation ranges from 60 inches in the far eastern portions of the state to ~ 9 inches in western portions.

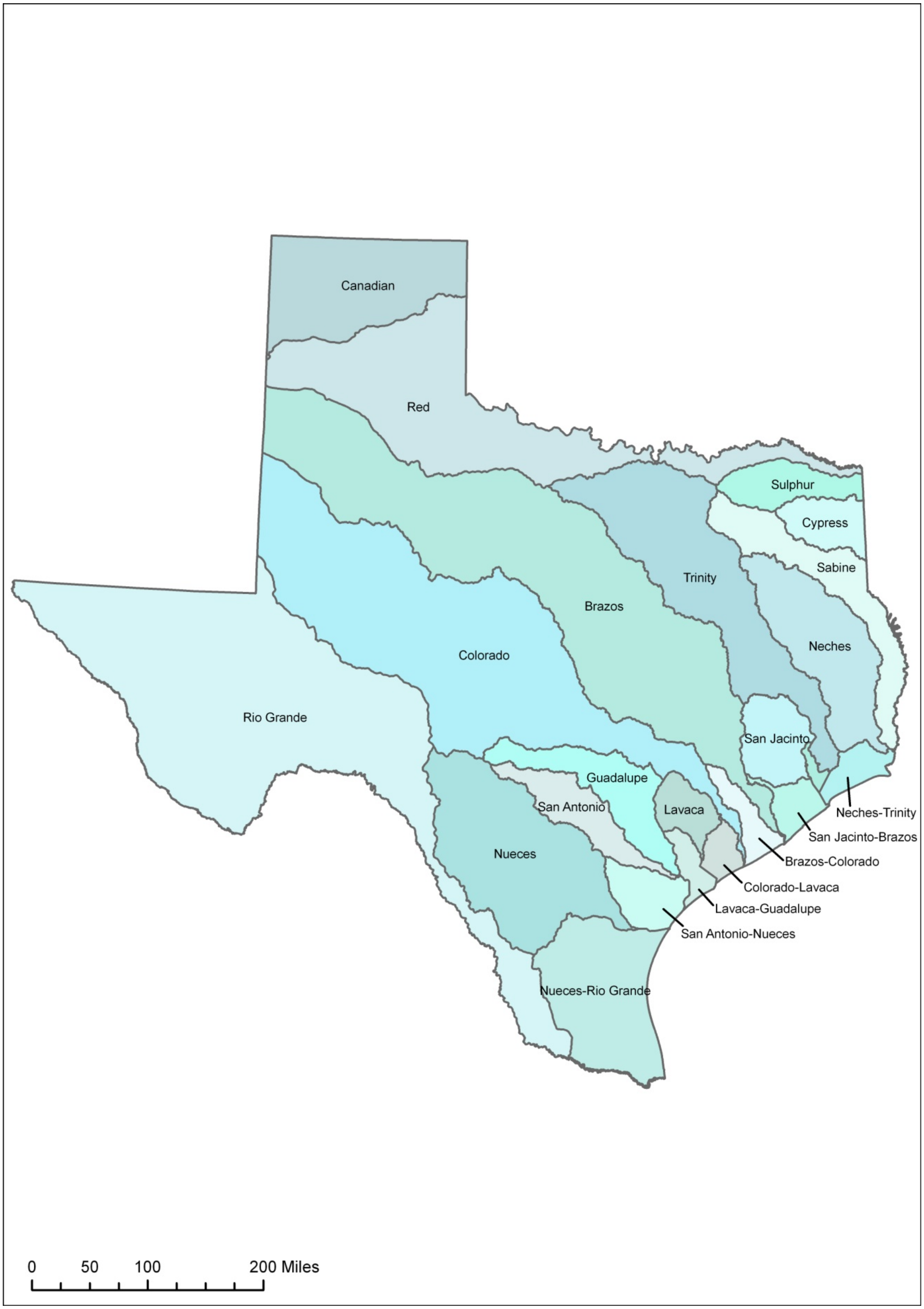

Figure 8. Major river basins in Texas

variations in flow, high turbidity (especially in the Trinity, Brazos, and Red River drainages), and harsh environmental conditions. Channel substrates are mostly soft, shifting sediments (sand, mud, and silt). The dominant physical structure within stream channels is large woody debris.

### *North-Central Texas*

North-central Texas rivers (Canadian, Upper Brazos, Upper Colorado, Upper Red, Upper Trinity) drain watersheds with clay-rich soils and heavy agriculture use. This region is drier than east Texas, with occasional severe droughts and rainfall averaging between 15 and 28 inches a year . These rivers have flow characteristics similar to those of East Texas rivers, but they are smaller and tend to experience more frequent drought conditions. The region is dominated by fish species that are resistant to alternating drought and flood conditions. Like east Texas, water-based recreation is also quite popular. This region includes several of the state's large metropolitan areas (Dallas/Forth Worth, Amarillo, Lubbock, Waco).

### *South-Central Texas*

This region is better known as "The Hill Country" of Texas. Rivers that drain this region include the Blanco, Comal, Frio, Guadalupe, Lower Colorado, Nueces, Sabinal, San Antonio, and San Marcos rivers. The landscape in this region is rocky in many areas, and the dominant land use in this region is livestock grazing. The region, which includes the Edwards Plateau, has a relatively wide range of average annual precipitation. Parts of this region are relatively dry and experience periodic drought, with average annual rainfall of around 10 inches, other parts receive up to about 40 inches a year. Rivers in the region receive significant subsurface flow and tend to flow clear and cool most of the time, but experience relatively infrequent flash floods during spates. The region harbors several threatened and endangered fishes including the fountain darter (*Etheostoma fonticola*), Clear Creek gambusia (*Gambusia heterochir*), and cave catfishes (*Satan eurystomus*, *Trogloglanis pattersoni*). Two of the state's fastest growing metropolitan areas, Austin and San Antonio, are located along this region's eastern border. The rapid population growth of these two urban areas has placed sharp demands on the region's limited water resources. Hill Country rivers and streams are used for a variety of recreational purposes, including swimming, rafting, canoeing, and fishing.

### *Lower Rio Grande Basin (Lower Rio Grande, Devils)*

The largest rivers in south Texas are the Lower Rio Grande River and its tributaries, including Devils River, Las Moras Creek, and San Felipe Creek. Annual average rainfall in this region varies from 11 to 26 inches. The region's prevalent land uses are irrigated row cropping in the Lower Rio Grande Valley, and livestock grazing across the region. The region's major cities are Brownsville, McAllen, and Del Rio. Population growth in this region also is exerting increasing pressure on limited water resources. Over the past several decades, instream flow in the Lower Rio Grande has been progressively reduced by upstream water diversion, withdrawal, and evaporation from reservoirs. Today, the Lower Rio Grande channel is periodically reduced to a series of isolated pools, and the river fails to reach the Gulf of Mexico for extended periods. The Rio Grande is an extreme example of how aquatic biota evolutionarily adapted to pre-Columbian stream flows have been stressed to the point where their survival is threatened by changes and disruptions to natural flows. Threatened and endangered aquatic species in this region include the Devils River minnow (*Dionda diaboli*), prosperine shiner (*Cyprinella proserpina*), and Rio Grande darter (*Etheostoma grahami*). Water-based recreation use is increasing on those rivers that have relatively reliable year-round flows.

### *West Texas*

West Texas is the driest region of the state. Some areas of west Texas receive annual average rainfall of roughly 16 inches, but that figure falls to less than 8 inches in far west Texas. The region's aridity has resulted in strong pressures on its surface and groundwater resources. The principal land use is livestock grazing, especially for sheep and goats. The principal rivers in this region are the middle Rio Grande and the Pecos. The Pecos River is highly saline and has experienced golden algae blooms that kill fish and other aquatic animals (Rhodes and Hubbs, 1992). Endangered aquatic species are a common occurrence and include the Comanche Springs pupfish (*Cyprinodon elegans*), Leon Springs pupfish (*C. bovinus*), Pecos pupfish (C. pecosensis), and Pecos gambusia (*Gambusia nobilis*).

## Threats Analysis

Williams et al. (1993) described threats to freshwater mussel conservation throughout North America, whereas Neck (1982) and Howells et al. (1996) summarized threats particular to Texas. Threats listed by Williams et al. (1993) include habitat destruction, overutilization for commercial or other purposes, disease, predation, introduction of non-indigenous species, pollution, hybridization, and restricted range. Among these, they prioritize habitat destruction and the expanded ranges of non-indigenous mollusks as being primary threats to freshwater mussels throughout North America.

Howells et al. (1996) draw attention to very early impacts on mussel populations from overharvesting, pollution, and habitat alteration that occurred prior to any substantial scientific interest in mussel conservation. They summarize more recent threats as including waterway modification, changes in stream beds, commercial mussel fisheries, water quality deterioration, sedimentation, agricultural runoff, industrial pollution, commercial barge activity, and competition with introduced Asian clams.

In his review of interactions between humans and freshwater mussels in Texas, Neck (1982) found that reservoir construction, land clearing, urban development, and groundwater withdrawal were major proximate causes of habitat and flow alteration.

Our own previous research on the biology of Texas freshwaters indicate four primary threats to mussel diversity and abundance: 1) urbanization affects on the hydrology and sediment dynamics of streams and rivers, 2) nutrient loading from both urban and agricultural sources, 3) water withdrawals and diversions of both subsurface and surface waters in areas of rapid population growth, and 4) introduction and range expansion of invasive species like loricariid catfishes (*Pterygoplichthys* sp, and *Hypostomus* sp.), and Asian clams (*Corbicula fluminea*).

## US Fish and Wildlife Service Five Factor Analysis

***Factor A***: *Present or threatened destruction, modification or curtailment of freshwater mussel habitat or range*

Freshwater mussels are sessile (bottom resting), fully aquatic organisms with a limited ability to survive out of water and respond to habitat dewatering via movement. With the exception of some pondhorn mussels (*Uniomerus* spp.) that can burrow to prevent desiccation, Texas mussels are restricted to permanent water bodies. Within these waters, mussels are highly variable in their tolerance of different flow regimes, substrate sizes, and water qualities. Mussels feed by actively filtering plankton from the water column and, in part because of this, mussel communities generally increase in abundance and species-richness along longitudinal gradients in rivers systems. Lentic environments such as slack-water river zones, lakes, and ponds also host abundant but relatively species poor mussel communities (Howells et al., 1996, Williams et al., 2008).

Mussel abundance and diversity is negatively correlated with extremely silty substrates or substrates composed of fine shifting sand. Only very light, thin-shelled mussels such as the paper pondshell (*Anodonta imbecillis*) can cope with rapid siltation (Howells et al., 1996). Sediments, which are considered by the EPA to be the number one pollutant in U.S. rivers, are therefore a leading threat to mussel diversity and abundance. In a study of Alabama streams, Gangloff et al. (2009) found mussel abundance and diversity to be positively correlated with the upstream presence of intact low-head or mill dams, and negatively correlated with breaches to such dams or weirs. They hypothesized that small impoundments upstream of mill dams positively influenced mussel assemblages in at least two ways: by preventing sediment from moving downstream and by providing an increased abundance of planktonic food items. Such apparent benefits to certain mussel species in areas below mill dams must be considered short term, because these structures can function as major barriers to dispersal by aquatic organisms in the long term.

Beyond the need for clean substrates, mussels do not appear to be particularly demanding of substrate size. A variety of substrate sizes, from stable sand, to clay, to gravel, to cobble bottoms can host mussels, and within this range, there is little evidence to suggest greater preference by mussel species for any particular substrate size (Williams et al., 2008). Proximity to substrate stabilizing features like logs or large boulders appears to be a slightly better predictor of mussel presence, which may also help explain the positive effect of mill dams on mussel assemblages (Howells et al., 1996, Williams et al., 2008). It should be noted that bedrock substrates, although stable, are generally negatively correlated with mussel abundance and diversity due to the lack of interstitial refugia in which mussels may reside.

Depth appears to be another general limiting factor for mussels, with mussel abundance and diversity dropping off rapidly below 7.6 m (Howells et al., 1996). Rapid and/or historical water level fluctuations in reservoirs may result in exceptions to this generality, though. Presence of large dams and the reservoirs and tailwaters they create, are negatively correlated with mussel abundance and diversity, likely due to reduced abundance of planktonic food sources in tailwaters, increased sedimentation in reservoirs, reduced oxygen, reduced and/or stabilized temperatures, and/or absence of host fish species (see Factor E; Howells et al., 1996, Williams et al., 2008). Temperature fluctuations are believed to be the main reproductive stimulus for mussels (Williams et al., 2008), thus the potential threat provided by temperature stabilization due to river impoundment.

***Factor B***: *Overutilization of species for commercial, recreational, scientific, or educational purposes*

North American freshwater mussels have likely been exploited commercially since well before 1891, when the first dedicated freshwater pearl button business was started in Muscatine, Iowa (Williams et al., 2008). The pearl button industry has waned since the advent of plastic substitutes, but commercial harvests of mussels continue to serve freshwater pearl, and seed pearl industries. In the latter, blanks are cut from freshwater mussel shell, then polished into spheres to be implanted into marine oysters to stimulate production of cultured pearls. Harvests of mussels for freshwater pearls have historically been episodic, largely in response to fluctuating demand, public awareness of demand, and rare discoveries of valuable pearls (Howells et al., 1996, Williams et al., 2008).

In aggregate, these harvests have historically and periodically severely impacted mussel beds in many areas of the country. Federal surveys of pearl fisheries in the late 19th century found mussel beds in localities across the east coast "completely exhausted" (Williams et al., 2008). By the late 20th century, Texas mussel beds were being exploited by commercial musselers from as far away as Oregon, Tennessee, and Illinois, presumably in response to the depletion of these musselers' local resources (Howells et al., 1996).

Commercial mussel harvests are typically regulated by a combination of 1) licenses limited by cost or number, 2) minimum take by size, and/or 3) maximum take by weight. With conservative application of these regulations, it is believed that freshwater mussels can be harvested sustainably (Williams et al., 2008). In Texas, commercial mussel harvest is regulated by the TPWD and interest in commercial harvest of Texas mussels appears to have increased substantially in the late 20th century. From 1963 to 1977 TPWD sold no more than about 3 annual licenses a year (Howells et al., 1996), but in 1977, over 200 licenses were issued, and 400-500 licenses were issued in subsequent years (Howells et al., 1996).

As of 2010, TPWD has placed a moratorium on the sale of new commercial licenses and is only renewing licenses of previous resident or non-resident fishermen holding licenses obtained from 2003 to May 1, 2006. Commercial harvests therefore appear to have been a significant historical threat to mussel populations in Texas, but these activities have recently been curtailed via increased regulation. Utilizations of mussels for recreational, scientific, or educational purposes are largely unreported and such uses likely have negligible impacts on mussels in Texas.

***Factor C***: *Disease or predation*

Freshwater mussel pathology has been poorly studied and there are few described mussel diseases (Howells et al., 1996, Williams et al., 2008). Mussel parasites though, in the form of various small mite and trematode genera and species, can be common in mussel tissues and fluids. Mites appear to pose relatively minimal threat to mussels, but trematodes can infest some individuals to the extent of replacing all gonadal tissue (Williams et al., 2008).

Freshwater mussels are consumed by a number of aquatic and terrestrial organisms. Juveniles and adults of species with weak shells are particularly susceptible to predation by aquatic predators, including crayfish, amphibians, turtles, and some fish (freshwater drum, bullhead catfish, flathead catfish, and channel catfish) and terrestrial predators, including birds (waterfowl, crows, Limpkin, Snail Kite, and Boat-tailed Grackle) and mammals (Pig, Raccoon, Muskrat, Mink, and River Otter). In addition to these native predators, the exotic black carp (*Mylopharyngodon piceus*) is a strongly molluscivorous fish known to have been employed for snail control in Texas aquaculture projects, but which has not yet been reported as established in the wild here (Nico et al., 1995).

Although effects of disease on mussels are poorly understood and poorly documented, predation on mussels by muskrats has been demonstrated to alter the species composition and size structure of mussel communities (Williams et al., 2008). In summary, given the apparently subtle effects of disease and parasites, and the limitation of most predators to shallow waters where smaller mussels should predominate, it seems likely that neither disease nor predation currently pose significant threats to the long-term persistence of mussel species. Establishment of breeding populations of black carp in the state's surface waters could change this threat assessment dramatically.

***Factor D***: *Inadequacy of existing regulatory mechanisms*

Regulatory mechanisms in Texas may mitigate or exacerbate threats to freshwater mussels in at least three ways: by controlling river flow dynamics, by controlling sediments entering rivers, and by controlling the direct take of mussels. Adequacy of existing regulatory mechanisms varies widely among these three.

Current water resource regulations in Texas have generally been developed without explicit consideration of mussel life history. This has been at least partly due to the paucity of studies on which to base decisions. Beyond the fact that mussels require wetted habitat, relationships between mussel life history and patterns of river hydrology are poorly understood. In one study of these relationships, Rypel et al. (2008) found that growth of mussel species in unaltered hydrologic settings is negatively correlated with high annual streamflow pulses, and positively correlated with the duration of periods with stable flow. Mussels inhabiting a hydrologically altered dam tailwater did not show such correlations.

Sedimentation of the stream bed is a leading threat to freshwater mussels and may be caused by a variety of human activities, including the construction of buildings and roads, the harvesting of timber, and agricultural practices including row cropping and livestock grazing. Numerous state, local and federal agencies regulate these activities in Texas with the goal of reducing sedimentation resulting from human impacts by recommending and enforcing best management practices such as sediment barriers or traps along stream corridors, retention ponds at construction sites, maintenance of forested riparian corridors, and reseeding following land clearing.

As discussed under Factor B above, commercial harvests have been a recent major threat to freshwater mussels in Texas. This activity is regulated by the TPWD, which has recently placed a moratorium on the sale of new licenses and is only renewing licenses of previous resident or non-resident fishermen holding licenses obtained from 2003 to May 1, 2006.

***Factor E***: *Other natural or anthropogenic factors affecting mussel survival and population persistence*

At least two additional dynamics must be considered as sources of potential threats to mussels: 1) relationships between mussels and fishes that act as hosts for their glochidia (parasitic mussel embryos), and 2) potentially negative competitive interactions with invasive exotic mussel species.

Freshwater mussels have complex life cycles. They are ovoviviparous, meaning that mussel embryos develop from eggs retained within the mother's body, and mussel embryos (referred to as glochidia) are obligate parasites that encyst themselves on the fins or gills of fishes or, rarely, amphibians. Glochidia that do not encyst themselves perish, and some fish species are capable of killing the encysted glochidia via immune reactions. Successful pairing between glochidia and a suitable, non-immune fish host, can therefore be a factor limiting the recruitment success of some mussel species. The glochidia of some mussel species are generalists and capable of encysting on a wide variety of host species, whereas the glochidia of other species may only be able to encyst themselves on a select few host species. Knowledge of mussel-host specificity is poor for most species of Texas mussels, although lists of known hosts are summarized by Howells et al. (1996).

Given these specialized relationships, conservation of most mussel species will also require conservation of their host fish species, and may require efforts to ensure that host fishes are proximate to target mussel species during their reproductive periods. This brings up a fourth potential reason why mill dams might be beneficial for mussel diversity and abundance in the short term (Gangloff et al., 2009): stream sections downstream of these barriers frequently serve as staging grounds for a wide variety of fish species during their upstream spawning migrations in spring, when many mussels are also reproducing. Of course, the benefits to mussels of these seasonal fish aggregations would be offset by the inability of glochidia-infected fishes to disperse upstream. In the long term, efforts should focus on correcting persistent threats such as sedimentation so that short term structures with long term costs such as mill dams are unnecessary.

Finally, two aggressively invasive and exotic bivalve species are known to be expanding their ranges in North America. The Asian clam (*Corbicula fluminea*) is already known to exist in all major drainages in Texas (Howells et al., 1996; K. Winemiller personal observations), and the zebra mussel (*Dreissena polymorpha*) is just beginning to be reported from at least one Texas reservoir (Lake Texoma, TPWD, 2009) and is likely to expand its range in the state. Although *Corbicula* are frequently encountered living alongside native mussels throughout North America, apparently without significant negative effects on the native fauna, potential for competitive interactions have been poorly studied. In contrast, zebra mussels occur in dense numbers and have been known to encrust all exposed hard surfaces, including the shells of native mussels. In these cases, the densities of zebra mussels were sufficiently high that it was assumed to be detrimental to the encrusted native mussels.

## Threats by Basin

### *Sabine/Neches*

Water quality issues are one of the main threats to aquatic biota in East Texas and Western Louisiana. For example, a recent Water Quality Inventory Report (LDEQ 2004) indicated that 47% of the 19 water body subsegments within the Sabine basin were fully supporting their three primary designated uses. 68% of the subsegments were supporting their designated use for fish and wildlife propagation. The suspected causes for these water quality problems include: metals, fecal coliform, non-native aquatic plants, organic enrichment and low concentration of dissolved oxygen, and turbidity. The suspected sources of the water quality problems include: major industrial point sources, harvesting/reforestation, surface mining, agriculture, and urban runoff.

The following were described as the main threats to aquatic life in the Sabine and Neches basins: Channelization, commercial/industrial development, construction of drainage and diversion ditches, conversion of forested land to agriculture, crop production practices, dam construction, development of roads and pipelines, excessive groundwater withdrawal, poor forestry practices, industrial discharge, invasive/alien species, dam operations altering hydrology, operation of diversion systems, and residential development (Louisiana Comprehensive Wildlife Conservation Strategy, Dec. 2005). In addition, the lower reaches of both rivers, the Neches in particular, are increasingly influenced by saltwater intrusion that may be a function of coastal subsidence and altered hydrology from dam operations.

### *Trinity/San Jacinto*

Urban development and water diversion impacts loom very large throughout this basin. Deforestation and agricultural development have impacts to aquatic ecosystems but these processes have probably neared a plateau in the basin. Urban and suburban growth continue at a rapid pace in the basin. Several direct impacts to watersheds and aquatic ecosystems result from this growth, including sedimentation, altered hydrology, pollution (both point source and non-point source). Road construction and increase in impervious land cover (concrete) makes hydrographs flashier, which in turn affects sediment dynamics and characteristics of the stream bed. This greatly influences mussels and other benthic organisms.

***Brazos***

The same issues facing the Trinity will affect the Brazos Basin. Sedimentation and nutrient loading are chronic issues for certain regions within the basin where cattle ranching and/or row crop agriculture are widespread. New reservoirs are also planned for tributaries of the middle and lower Brazos River.

***Colorado-Guadalupe-San Antonio-Nueces (priority)***

Water supply issues will continue to pose conservation challenges in the Colorado, Guadalupe, San Antonio and Nueces basins, so there will be great need to understand environmental flow needs of aquatic biota including mussels. Urban/suburban growth continues at a rapid pace in each of these basins, and a familiar suite of impacts to aquatic ecosystems accompanies this growth (changes in runoff patterns, nutrient and sediment delivery, hydrology, etc.).

***Rio Grande***

Rivers and streams of the Rio Grande basin have faced a number of severe impacts for several decades, and the future will not likely bring significant relief. Water supply issues and invasive exotic species pose the greatest threats to aquatic life in the region. Pumping of groundwater, water diversion for irrigation, and impoundment by reservoirs have had negative effects on native biodiversity. The Rio Grande basin contains many endemic aquatic species, and a significant number of these are threatened or already extinct. Although mussel diversity is not high compared with other basins in the state, the threats to species in the Rio Grande basin are assumed to be severe (based on impacts documented to fishes and other aquatic taxa).

## Future Research Priorities

Several research programs are proposed herein, each serving as opportunities to complement recent, ongoing research on Texas mussels, and to maximize contributions to critically unknown aspects of Texas' most imperiled mussels:

***1) Taxonomic verification of the Texas Freshwater Mussel Database (TFMD):***

In late 2009 and early 2010, staff of the Texas A&M University Department of Wildlife and Fisheries Sciences queried records of Texas freshwater mussels (Unionidae) from 15 institutional biodiversity collections in the United States and Canada. Results of these queries were standardized and compiled into the TFMD, which consists of 7442 records dating from 1829 to 2005. These records subsequently were georeferenced by staff of the Institute of Renewable Natural Resources at Texas A&M. Unfortunately, potential errors in the original identification of voucher material backing these records will limit the value of this database until recognized experts in the taxonomy of Texas freshwater mussels can review these specimens, or a subset of vouchers from collections, to verify their identifications (Figure 9). Via examination of maps generated from the georeferenced database records, extra-limital historical records can be flagged and requested as loans from the institutions where they are archived. Once these loans have been accumulated in a single location, taxonomic experts could be enlisted, perhaps on a contractual basis, to examine the material. The species identifications for the examined specimens would then provide a basis for verifying all or nearly all records contained in the current TFMD database.

***2) Survey of Low-head (mill) Dams in Texas:***

From 2006-2008, personnel from Auburn University surveyed mussel and fish populations associated with a randomized subset of low-head dams in Alabama (Gangloff et al., 2009). They found that mussel diversity and abundance was positively correlated with the upstream presence of intact low-head dams, and negatively correlated with breaches to such dams. For a variety of reasons enumerated in the threats analysis above,

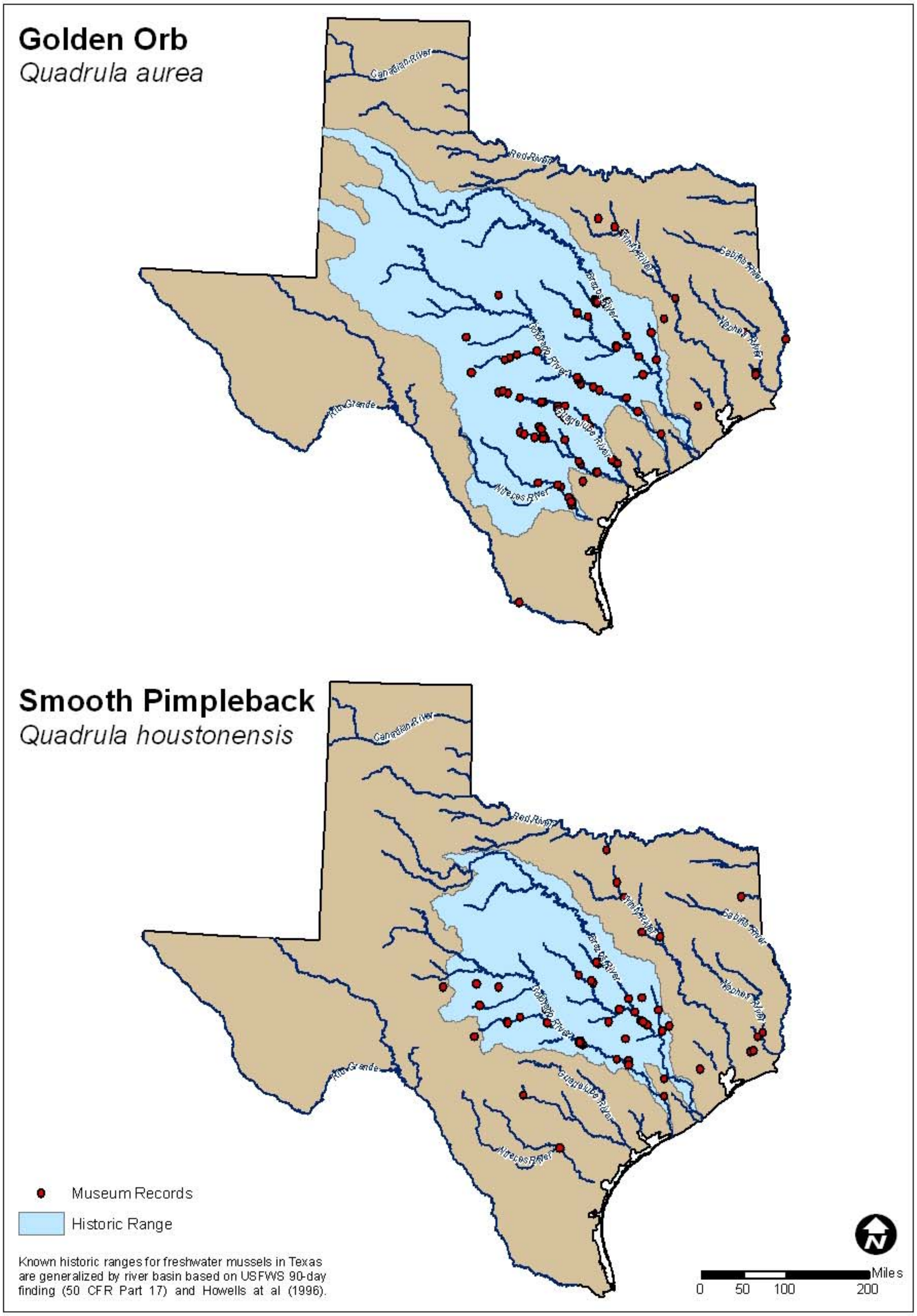


Figure 9. Examples of museum records that may serve to expand the known range of a species or highlight misidentified voucher specimens that need verification.

this pattern is consistent with our understanding of several critical aspects of mussel life history. As along the Fall Line of Alabama, low-head dams in Texas are most abundant in areas of transition from uplands to lowlands of the coastal plane. In Texas, these transitional zones are concentrated around the central Texas highlands (Edwards Plateau). We propose a study similar to that conducted in Alabama, replicating their methods and comparing results.

***3) Mussel Host Species:***

An obvious potential threat to the long-term persistence of mussel populations in Texas rivers and streams is disruption of the critical relationship between mussel glochidia and their host species of fishes. Without establishment on the gills, bodies, or fins of a fish, the glochidia perish. If all glochidia perish, then obviously the population fails to recruit any new individuals into the population, and the population declines. Therefore, any disruptive factor that breaks this interspecific linkage is extremely detrimental to the persistence of freshwater mussel populations in Texas and throughout North America. In addition, any environmental factor or anthropogenic impact to fluvial ecosystems that reduces the ability of fishes to move through the system longitudinally will negatively impact the spatial distributions of mussel populations. Because the adult life stage of mussels has low mobility, mussels have come to rely on the relationship between their glochidia and their fish hosts to achieve dispersal over larger spatial scales within fluvial networks. Given that habitat disturbances in the form of bed scouring from high flow pulses is a natural and essential feature of fluvial ecosystems, it is reasonable to assume that freshwater mussels conform to a meta-population model in which local sub-populations contribute and receive migrants from each other. Thus, if one habitat patch or stream reach is negatively affected by bed scouring (or any other environmental impact), it is likely that others persist and can contribute recruits that may recolonize that patch. Given the dependency of mussel populations on the mussel-fish ecological relationship, it is essential to recognize requirements to maintain fish species diversity and abundance in rivers and streams that support mussel populations, and to maintain some degree of longitudinal connectivity of the fluvial ecosystems. Research is needed to establish the host-specificity of Texas mussel species, and to determine the dynamics of glochidia dispersal by fishes, and recruitment of young mussels into suitable habitats

***4) Documentation of Habitat Suitability for Texas Mussel Species***

An essential step in ecological research that has the objective to conserve wildlife is to establish the features of essential habitat for the species of interest. Habitat suitability has been examined and established fairly well for a variety of North American freshwater and coastal marine fishes. Unfortunately, given the lack of detailed field studies on the habitat and population status of unionid mussels, very little is understood about what constitutes good, marginal, or unacceptable habitat for these organisms. This situation is true throughout the continent, but investigators are beginning to conduct these studies in some states, particularly in the southeastern U.S. where unionid mussel diversity is highest. Badly needed in Texas is basic research that reveals patterns of distribution and abundance of mussel populations in relation to key characteristics of in stream habitat.

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## Appendix A

## Bibliography for Mussels in Texas

## Bibliography

We include herein a list of 169 references with particular relevance to freshwater mussels in Texas, dating from 1855 to 2009. Many of these references, particularly those from the last half of the 19th and first half of the 20th centuries, are taxonomic or systematic in focus – dealing mostly with species descriptions and generic affiliations. The ecology, biology, and conservation of Texas Freshwater Mussels have received increased attention more recently. We also include with this report digital copies of approximately 80 of the references listed.


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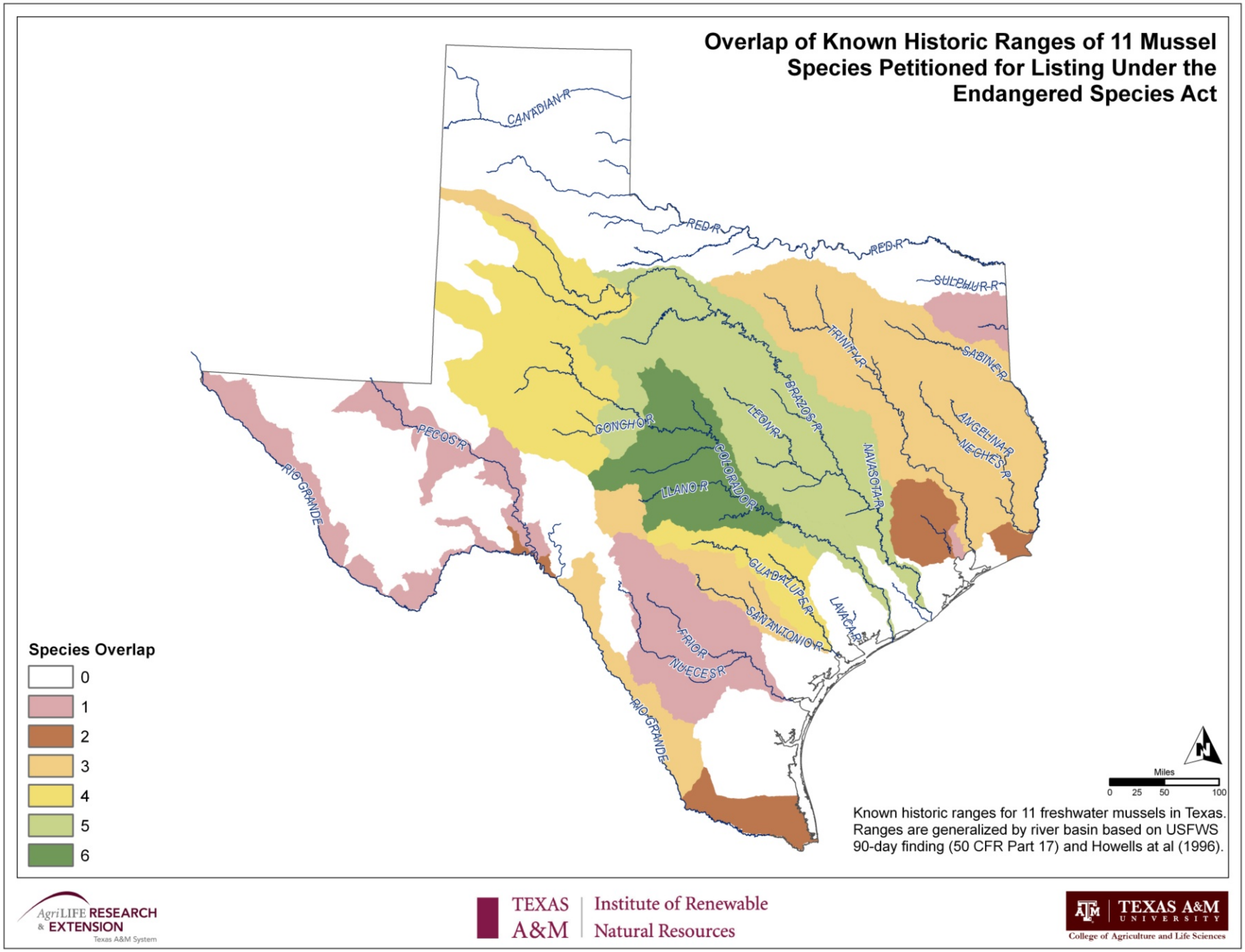
## Appendix B

## Maps of Interest



Overlap of Known Historic Ranges of 11 Mussel Species Petitioned for Listing Under the Endangered Species Act
CANADIAN R
RED R
RED R
SULPHUR R
TRINITY R
SABINE R
ANGELINA R
NECHES R
BRAZOS R
LEON R
NAVASOTA R
CONCHO R
COLORADO R
LLANO R
PECOS R
RIO GRANDE
GUADALUPE R
SAN ANTONIO R
LAVACA R
FRIO R
NUECES R
RIO GRANDE
Species Overlap
0
1
2
3
4
5
6
Miles
0 25 50 100
Known historic ranges for 11 freshwater mussels in Texas. Ranges are generalized by river basin based on USFWS 90-day finding (50 CFR Part 17) and Howells at al (1996).
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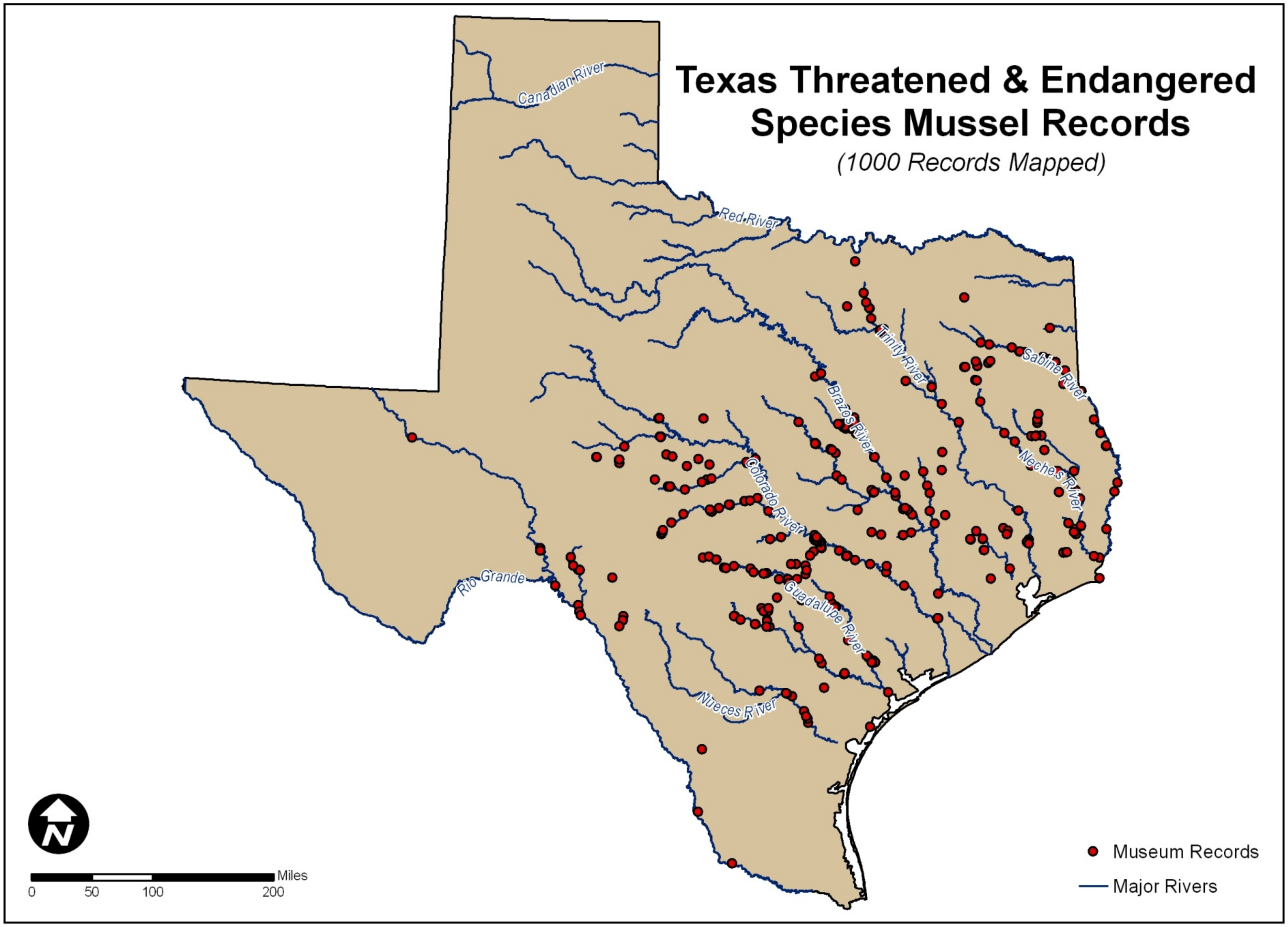
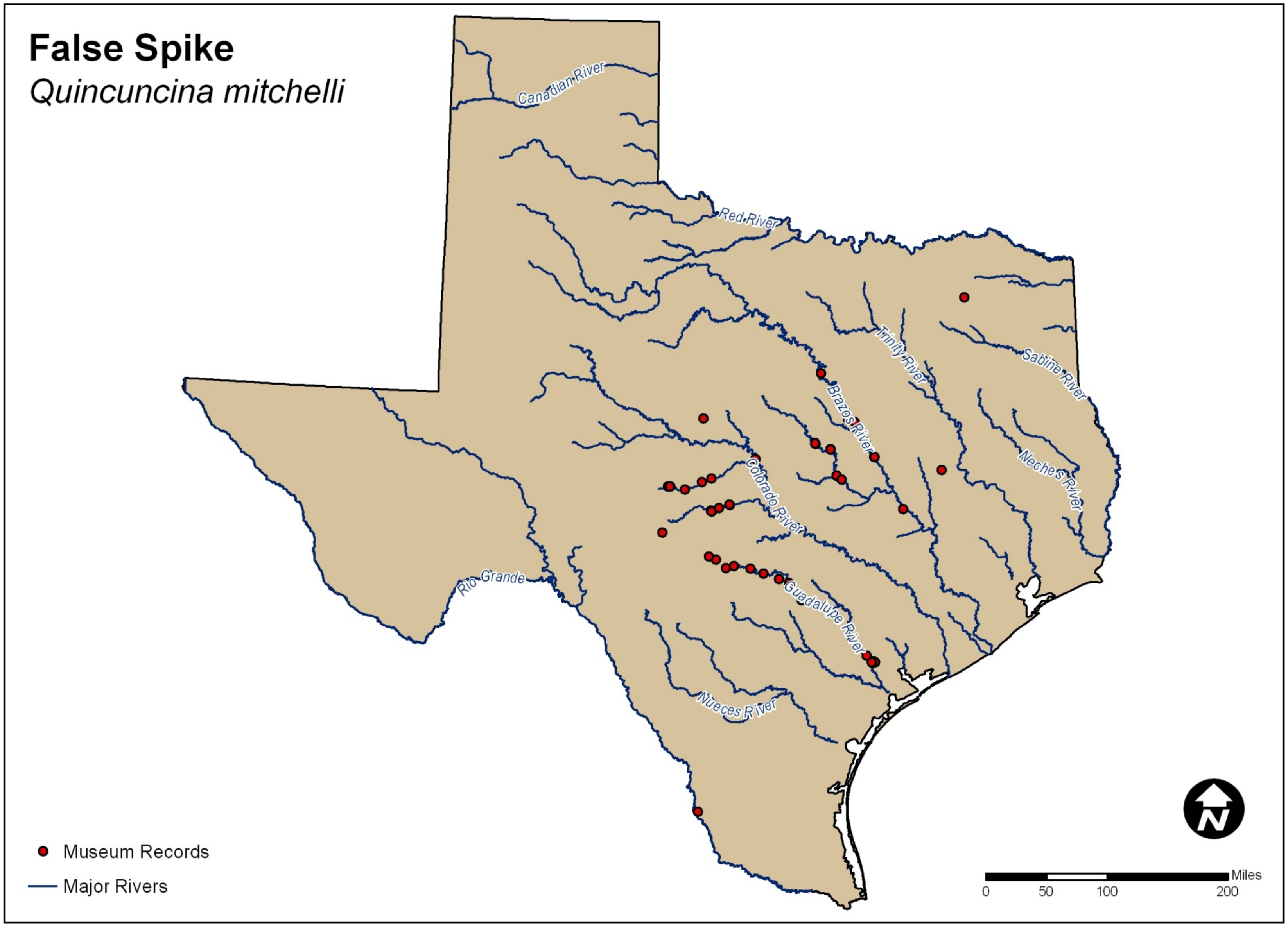
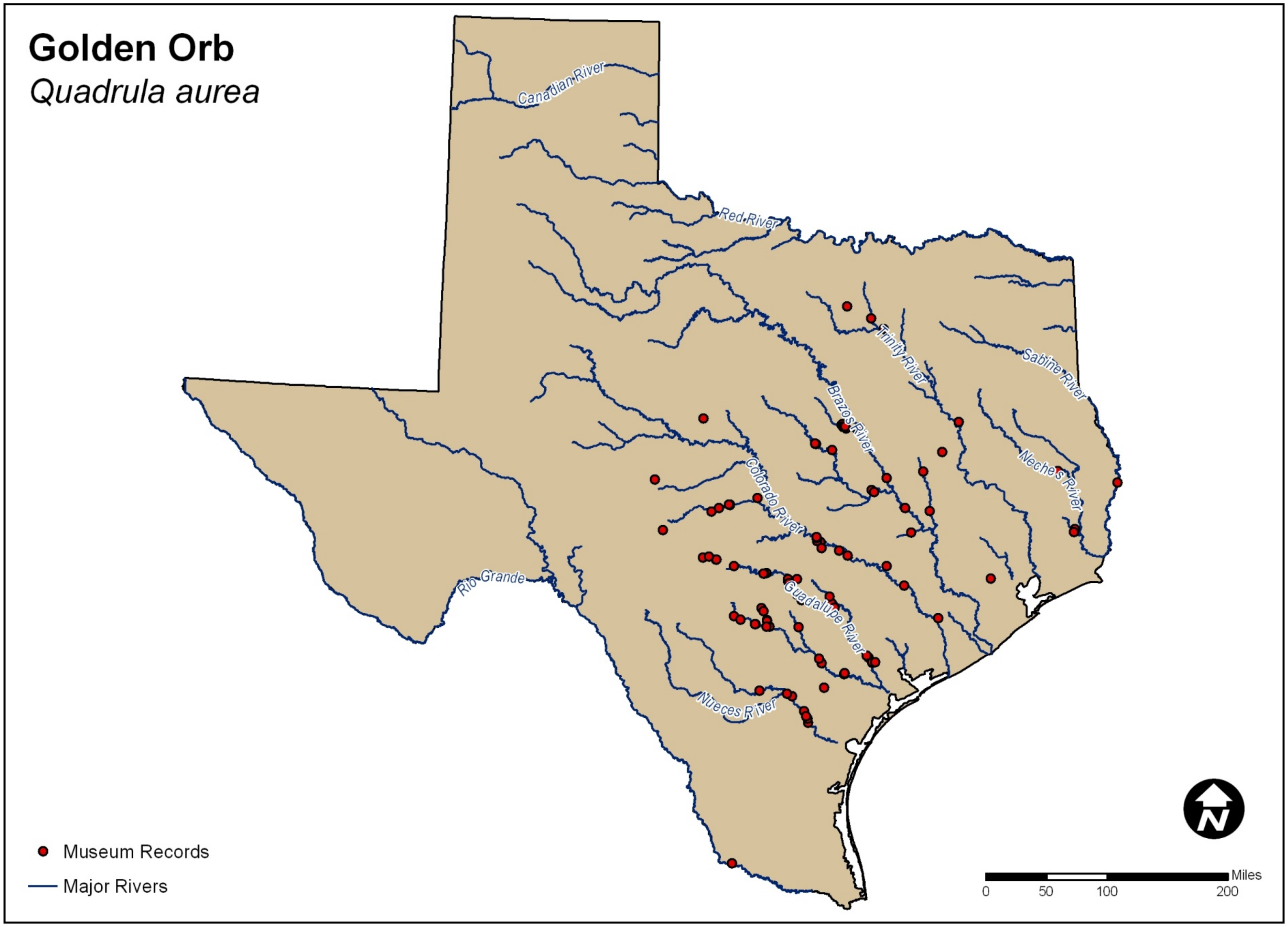
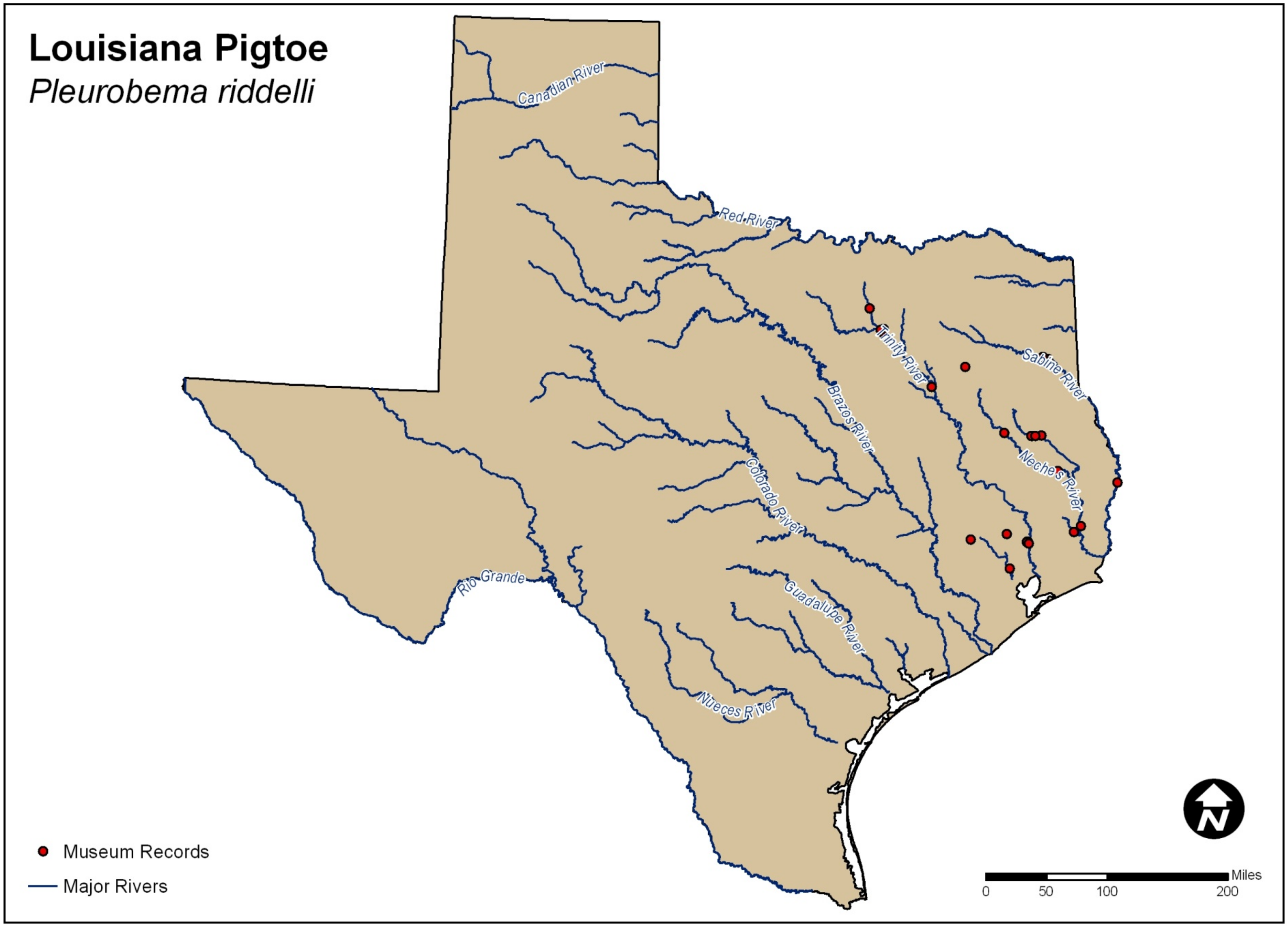
Texas A&M System
TEXAS A&M
Institute of Renewable Natural Resources
TEXAS A&M UNIVERSITY
College of Agriculture and Life Sciences

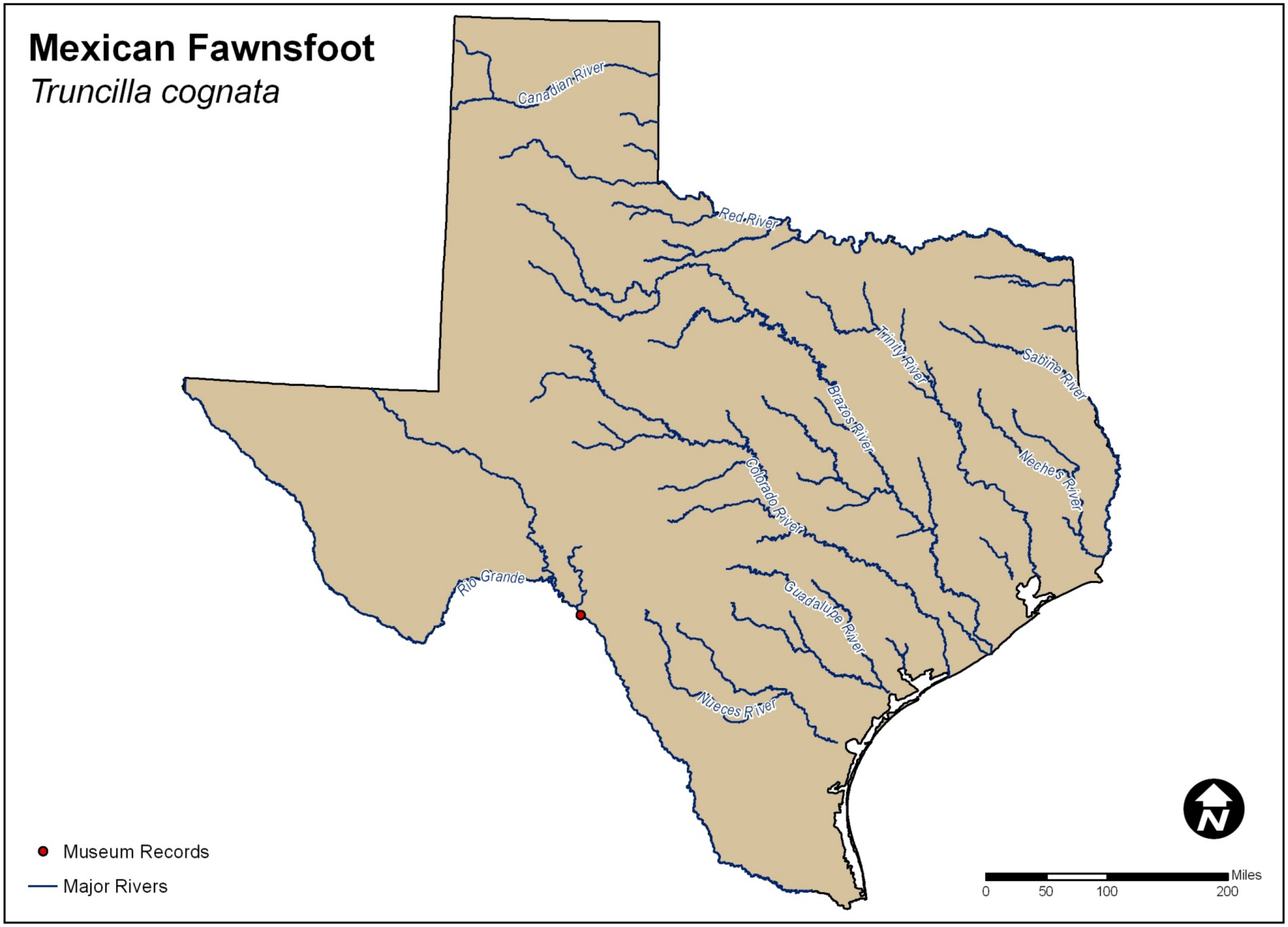

Texas Threatened & Endangered Species Mussel Records
(1000 Records Mapped)
Canadian River
Red River
Trinity River
Sabine River
Brazos River
Neches River
Colorado River
Rio Grande
Guadalupe River
Nueces River
Museum Records
Major Rivers
Miles
0
50
100
200


False Spike
Quincuncina mitchelli
Canadian River
Red River
Trinity River
Sabine River
Brazos River
Neches River
Colorado River
Rio Grande
Guadalupe River
Nueces River
Museum Records
Major Rivers
Miles
0
50
100
200

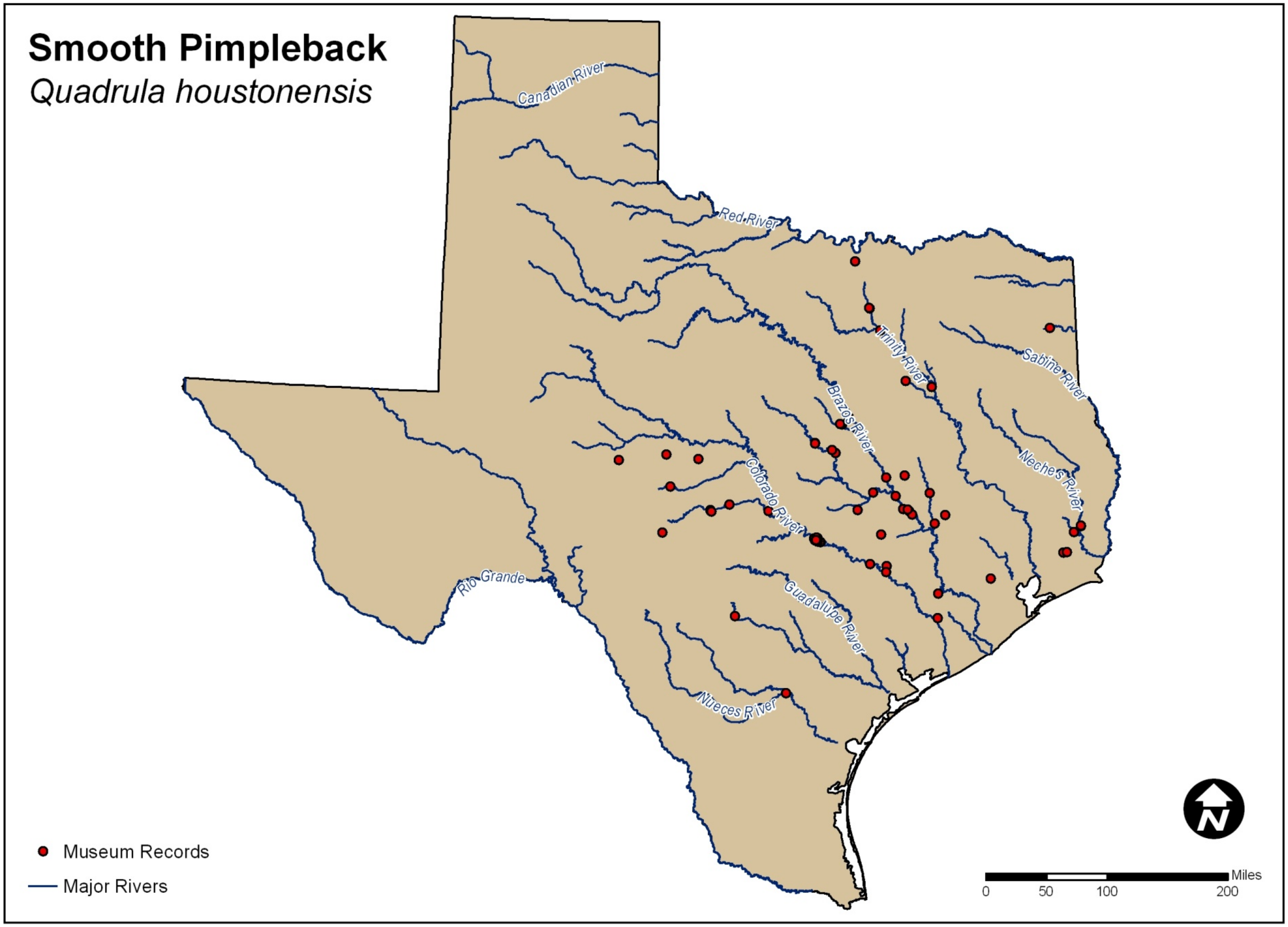


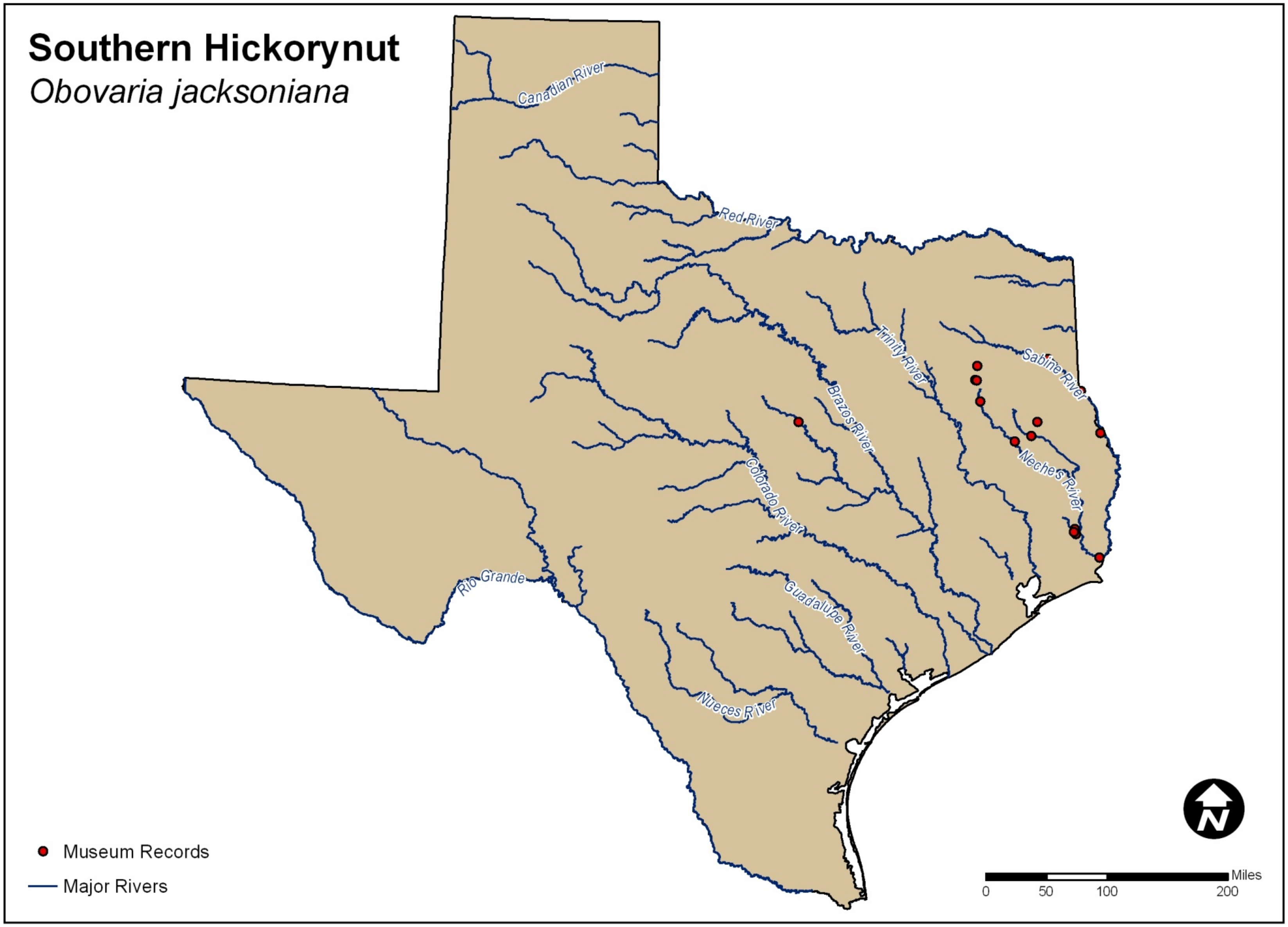
Golden Orb
Quadrula aurea
Canadian River
Red River
Trinity River
Sabine River
Brazos River
Neches River
Colorado River
Rio Grande
Guadalupe River
Nueces River
Museum Records
Major Rivers
Miles
0
50
100
200


Louisiana Pigtoe
Pleurobema riddelli
Canadian River
Red River
Trinity River
Sabine River
Brazos River
Neches River
Colorado River
Rio Grande
Guadalupe River
Nueces River
Museum Records
Major Rivers
Miles
0
50
100
200

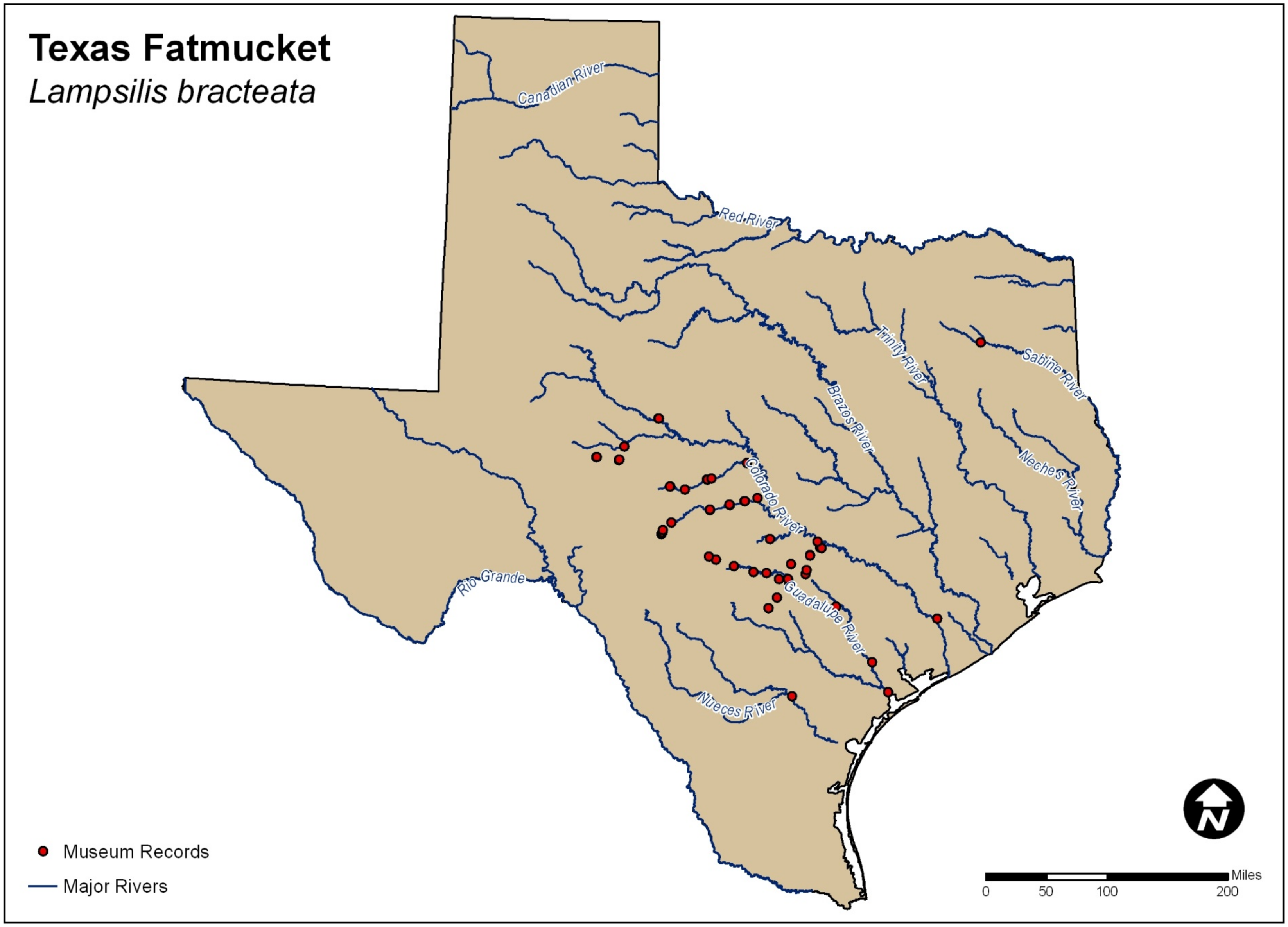


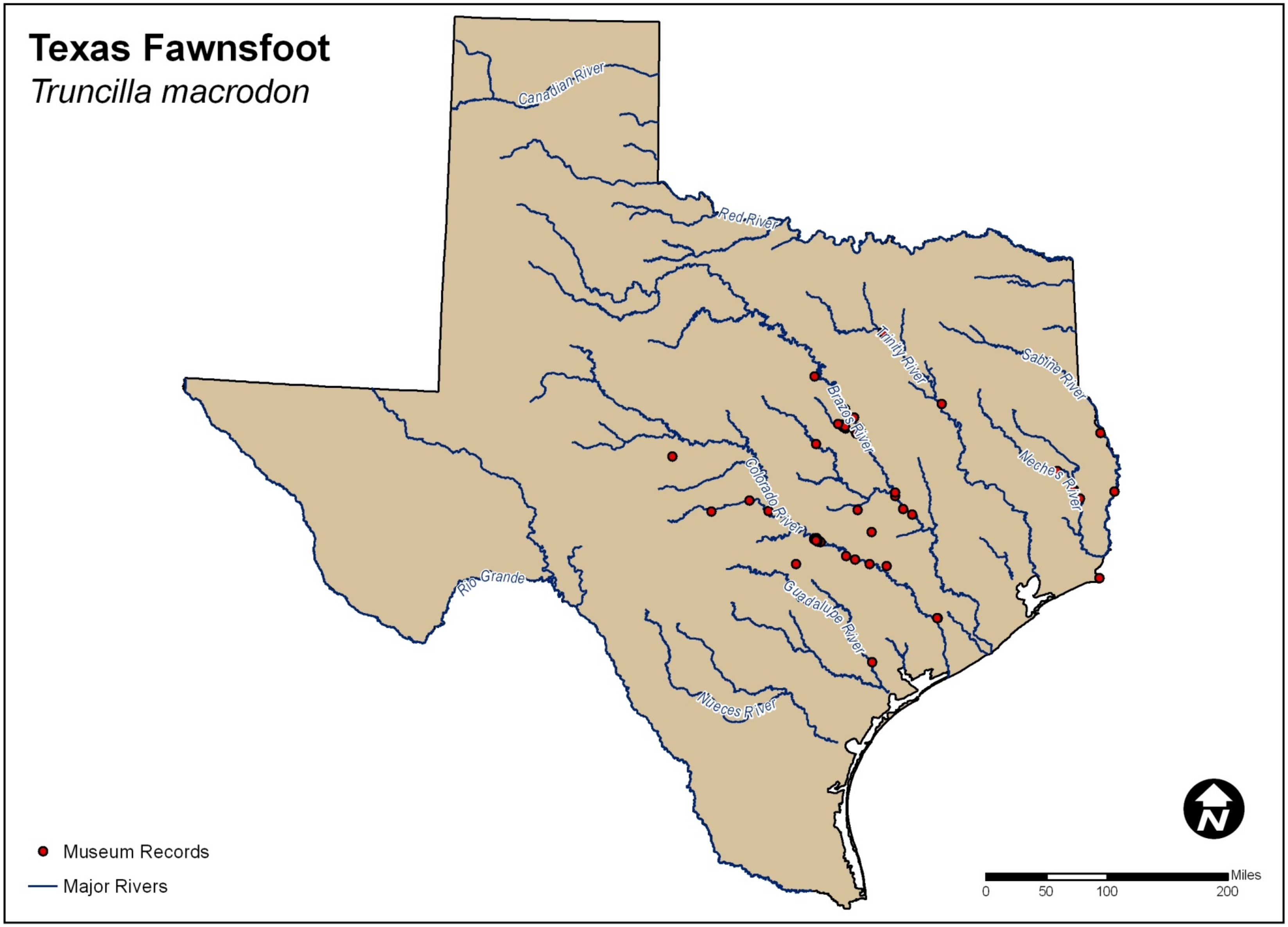
Mexican Fawnsfoot
Truncilla cognata
Canadian River
Red River
Trinity River
Sabine River
Brazos River
Neches River
Colorado River
Rio Grande
Guadalupe River
Nueces River
Museum Records
Major Rivers
Miles
0
50
100
200

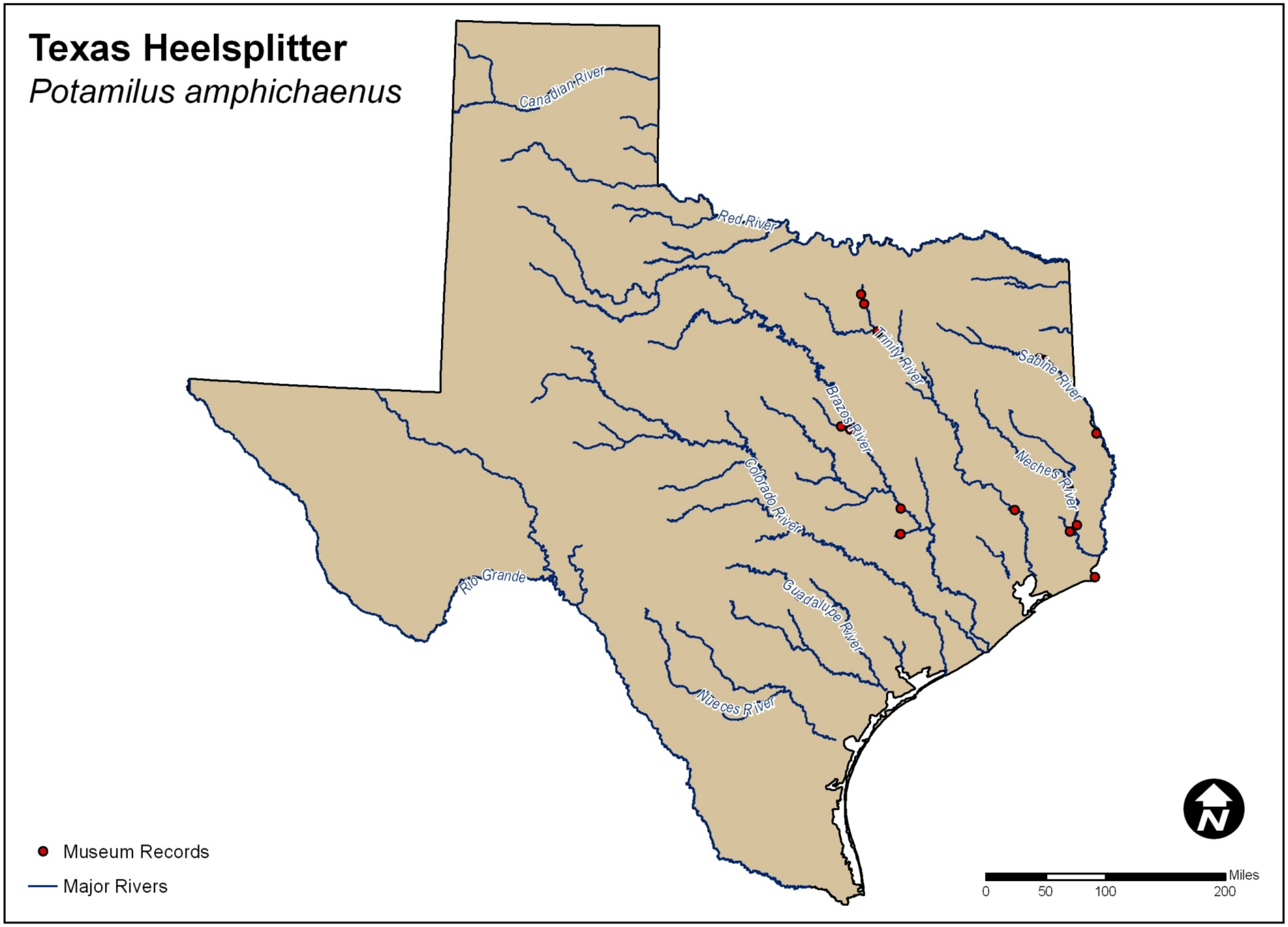

Smooth Pimpleback
Quadrula houstonensis
Canadian River
Red River
Trinity River
Sabine River
Brazos River
Colorado River
Neches River
Rio Grande
Guadalupe River
Nueces River
Museum Records
Major Rivers
Miles
0
50
100
200



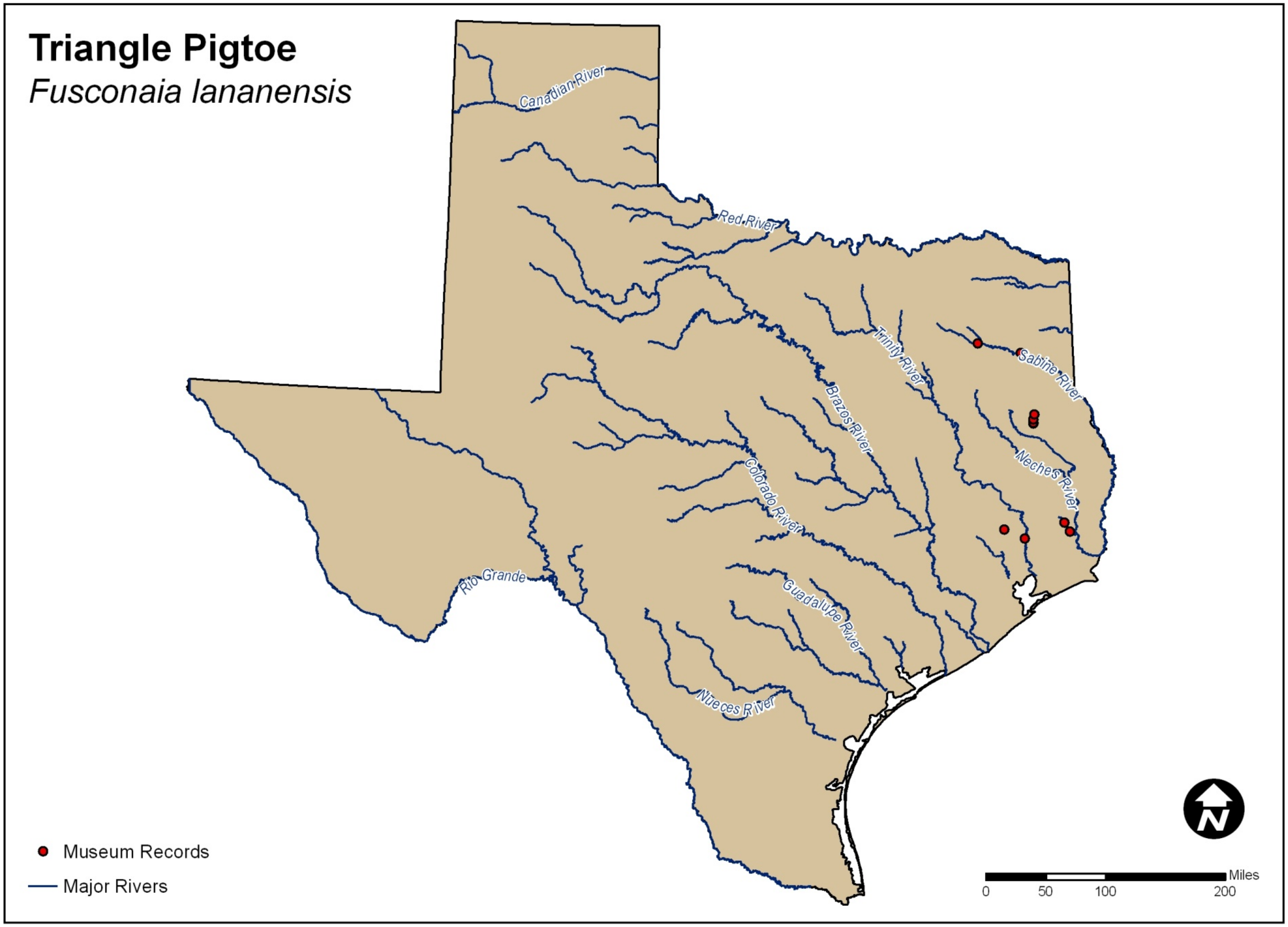
Southern Hickorynut
*Obovaria jacksoniana*
Canadian River
Red River
Trinity River
Sabine River
Brazos River
Neches River
Colorado River
Rio Grande
Guadalupe River
Nueces River
Museum Records
Major Rivers
Miles
0
50
100
200
N


Texas Fatmucket
Lampsilis bracteata
Canadian River
Red River
Trinity River
Sabine River
Brazos River
Neches River
Colorado River
Rio Grande
Guadalupe River
Nueces River
Museum Records
Major Rivers
Miles
0
50
100
200
N


Texas Fawnsfoot
Truncilla macrodon
Canadian River
Red River
Trinity River
Sabine River
Brazos River
Neches River
Colorado River
Rio Grande
Guadalupe River
Nueces River
Museum Records
Major Rivers
Miles
0
50
100
200
N



Texas Heelsplitter
*Potamilus amphichaenus*
Canadian River
Red River
Trinity River
Sabine River
Brazos River
Neches River
Colorado River
Rio Grande
Guadalupe River
Nueces River
Museum Records
Major Rivers
Miles
0
50
100
200


Triangle Pigtoe
Fusconaia lananensis
Canadian River
Red River
Trinity River
Sabine River
Brazos River
Neches River
Colorado River
Rio Grande
Guadalupe River
Nueces River
Museum Records
Major Rivers
Miles
0
50
100
200

# Appendix C

## Summary of Mussel Species by River Basin

| Species | Brazos | Brazos-Colorado | Canadian | Colorado | Colorado-Lavaca | Cypress | Guadalupe | Lavaca | Lavaca_Guadalupe | Neches | Neches-Trinity | Nueces | Nueces-Rio Grande | Red | Rio Grande | Sabine | San Antonio | San Antonio-Nueces | San Jacinto | San Jacinto-Brazos | Sulphur | Trinity | Trinity-San Jacinto |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ambiguous synonymy | 31 | 1 | | 39 | | 3 | 24 | | 3 | 25 | 4 | 8 | 2 | 4 | 2 | 19 | 5 | 1 | 19 | 3 | | 26 | |
| Bankclimber | | | | | | 11 | 2 | | | 48 | 2 | | | | | 22 | | | 6 | | | 34 | |
| Bleufer | 50 | | | 100 | | 4 | 6 | | | 25 | 1 | 1 | 1 | | 2 | 13 | 1 | | 13 | | | 33 | |
| Deertoe | | | | | | 1 | | | | 3 | | | | | | 8 | | | 6 | | | 14 | |
| False Spike | 16 | | | 42 | | | 33 | | 2 | | | | | | 1 | | | | | | 1 | 2 | |
| Fawnsfoot | 3 | | | 1 | | | | | | | 1 | | | 2 | | 2 | | | 1 | | | 2 | |
| Flat Floater | | | | | | | 3 | | 2 | 11 | | | | | | | | | 6 | | | 1 | |
| Fragile Papershell | 99 | | | 40 | | | | | | 13 | | | | 4 | | 9 | | | 6 | | | 28 | |
| Giant Floater | 52 | 1 | | 35 | | 7 | 57 | 6 | 9 | 34 | 1 | 14 | | 2 | 7 | 7 | 9 | 9 | 34 | 3 | 2 | 53 | |
| Golden Orb | 45 | | | 29 | | | 45 | | 5 | 3 | | 10 | | | 1 | 1 | 37 | 1 | 1 | | | 5 | |
| Gulf Mapleleaf | 5 | | | | | | 1 | | | 34 | | | | | | 4 | | | 1 | | | 10 | |
| Lampsillis vesicularis | | | | | | | | | | | | | | | | | | 1 | | | | | |
| Lilliput | 26 | 2 | | 23 | | 6 | 46 | 1 | | 3 | 1 | 10 | 5 | | 4 | 3 | 12 | 1 | 5 | | | 12 | |
| Little Spectaclecase | | | | 3 | | | | | 1 | 41 | 1 | 1 | | | | 9 | | | 11 | | | 25 | |
| Louisiana Fatmucket | 8 | | | 1 | | 1 | 9 | | 3 | 126 | | | | 1 | | 20 | 5 | | 13 | | 3 | 116 | |
| Louisiana Pigtoe | | | | | | | | | | 16 | | | | | | 4 | | | 4 | | | 25 | |
| Mapleleaf | 85 | 1 | | 61 | | 5 | 6 | 2 | 7 | 16 | 1 | 3 | | 7 | 4 | 7 | 4 | 1 | 6 | | | 26 | |
| Mexican Fawnsfoot | | | | | | | | | | | | | | | 2 | | | | | | | | |
| Paper Pondshell | 22 | 2 | | 21 | | 3 | 25 | 1 | 4 | 3 | | 8 | 10 | | 12 | 8 | 13 | 5 | 12 | 1 | | 16 | |
| Pimpleback | 21 | | | 1 | | 3 | 1 | | | 12 | | 1 | | | | 14 | | | 2 | | | 33 | |
| Pink Papershell | 170 | | | 55 | | | 18 | | | 8 | | | | 9 | | | 2 | | 7 | 1 | | 15 | |
| Pistolgrip | 32 | | | 44 | | | 12 | | 1 | 28 | | | | | 1 | 18 | 3 | | | | | 27 | |
| Plain Pocketbook | | | | | | | | | | 3 | | | | 1 | | 4 | | | | | | | |
| Pond Mussel | 10 | | | 6 | | 5 | 8 | 4 | 1 | 14 | | | | 1 | 1 | 4 | 1 | | | | 1 | 1 | |
| Pondhorn | 422 | 3 | 2 | 5 | 1 | 8 | 8 | 2 | 3 | 16 | 2 | 12 | 3 | 6 | 2 | 16 | 4 | 1 | 9 | 2 | 6 | 50 | |

| Species | Brazos | Brazos-Colorado | Canadian | Colorado | Colorado-Lavaca | Cypress | Guadalupe | Lavaca | Lavaca_Guadalupe | Neches | Neches-Trinity | Nueces | Nueces-Rio Grande | Red | Rio Grande | Sabine | San Antonio | San Antonio-Nueces | San Jacinto | San Jacinto-Brazos | Sulphur | Trinity | Trinity-San Jacinto |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Rio Grande Monkeyface | | | | | | | 4 | | | | | | | | 1 | | | | | | | | |
| Rock-Pocketbook | 6 | | | 5 | | | 1 | | | 15 | | | | | | 5 | | | 10 | | | 12 | |
| Round Pearlshell | | | | | | 1 | 5 | 2 | 3 | 10 | | | | | 2 | | | | 14 | | | 2 | |
| Sandbank Pocketbook | | | | 1 | | | | | | 13 | 1 | | | | | 14 | | | 7 | | | 1 | |
| Smooth Pimpleback | 28 | 1 | | 59 | | 1 | | | | 6 | 2 | 2 | | | | | 1 | | 1 | | | 17 | |
| Southern Hickorynut | 1 | | | | | | | | | 14 | 1 | | | | | 4 | | | | | | | |
| Southern Mapleleaf | 34 | | | 71 | | 2 | 12 | 2 | 4 | 12 | 4 | 13 | | | 2 | 2 | 3 | | 25 | | | 26 | |
| Spike | | | | | | 1 | | | | | 1 | | | | | | 1 | | 2 | | | | |
| Squawfoot | 2 | | | 9 | | 2 | | | | 3 | | | | | | 3 | | | 5 | | | 6 | |
| Tampico Pearlymussel | 164 | | | 136 | | | 62 | | 7 | | | 38 | 42 | | 28 | 1 | 33 | 6 | 1 | | | 9 | |
| Tapered Pondhorn | 6 | | | 1 | 1 | | | 1 | | 13 | 1 | | | 1 | | | | | | 1 | | 5 | |
| Texas Fatmucket | | | | 80 | | | 28 | | | 2 | | 1 | | | | 1 | 2 | 1 | | | | | |
| Texas Fawnsfoot | 40 | | | 42 | | | 6 | | | 4 | 1 | | | | | 3 | | | | | | 3 | |
| Texas Heelsplitter | 7 | | | | | | | | | 9 | 2 | | | | | 3 | | | | | | 6 | |
| Texas Hornshell | | | | 2 | | | | | | | | 1 | | | 31 | | | | | | | | |
| Texas Lilliput | 103 | 2 | | 24 | | 4 | 102 | 1 | 8 | 7 | 2 | 10 | 2 | | 5 | 4 | 13 | 6 | 39 | 1 | 1 | 63 | |
| Texas Pigtoe | 3 | | | | | | 1 | | | 33 | | | | | | 32 | | 1 | 10 | | | | |
| Texas Pimpleback | | | | 79 | | | 20 | | | 1 | 4 | | | | | | 1 | | | | | 2 | |
| Threehorn Wartyback | | | | | | 1 | | | | 11 | 1 | | | | | 14 | | | | | | 8 | |
| Threeridge | 80 | 2 | | 169 | | 1 | 110 | | 5 | 62 | 4 | 1 | | 1 | 3 | 18 | 62 | 1 | 31 | 1 | 2 | 102 | 1 |
| Triangle Pigtoe | | | | | | | | | | 23 | | | | | | 4 | | | 1 | | | 4 | |
| Wabash Pigtoe | 2 | | | | | 1 | 2 | | | 8 | | | | | | 25 | | | 2 | | | 124 | |
| Wartyback | | | | | | 2 | | | | 5 | 1 | | | | | 9 | | | | | | | |
| Washboard | 8 | | | 1 | | 1 | 10 | | 1 | 6 | | 5 | | | | 13 | 7 | | 5 | | | 9 | |
| Western Pimpleback | 2 | | | | | 1 | | | | 55 | | | | | | 7 | | | 16 | | | 65 | |

| Species | Brazos | Brazos-Colorado | Canadian | Colorado | Colorado-Lavaca | Cypress | Guadalupe | Lavaca | Lavaca_Guadalupe | Neches | Neches-Trinity | Nueces | Nueces-Rio Grande | Red | Rio Grande | Sabine | San Antonio | San Antonio-Nueces | San Jacinto | San Jacinto-Brazos | Sulphur | Trinity | Trinity-San Jacinto |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| White Heelsplitter | 1 | | | | | | | | | | | | | | | | | | | | | | |
| Yellow Sandshell | 110 | 1 | | 55 | | 3 | 25 | 1 | 3 | 43 | 1 | 17 | 25 | | 11 | 20 | 9 | 1 | 28 | | | 58 | |
| **Total** | **1694** | **16** | **2** | **1240** | **2** | **78** | **692** | **23** | **72** | **837** | **40** | **156** | **90** | **39** | **122** | **374** | **228** | **36** | **359** | **13** | **16** | **1076** | **1** |

**Appendix D**

**Descriptions of Museum Acronyms Used in the Texas Freshwater Mussel Database**

| Acronym | Museum |
|---|---|
| CMNML | Canadian Museum of Nature Mollusk Collection |
| AUM | Auburn University Museum |
| FMNH | Field Museum of Natural History |
| CMNH | Carnegie Museum of Natural History |
| INHS | Illinois Natural History Survey |
| DMNS | Dallas Museum of Nature and Science |
| UA | University of Alabama |
| DMNH | Delaware Museum of Natural History |
| FLMNH | Florida Museum of Natural History |
| MCZ | Museum of Comparative Zoology, Harvard |
| ANSP | Academy of Natural Science, Philadelphia |
| UMMZ | University of Michigan Museum of Zoology |
| USNM | United States National Museum |
| OSM | Ohio State Museum |
| BU-MMC | Baylor University, Mayborn Museum Complex |

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