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# HISTORY OF SPREAD AND CURRENT DISTRIBUTION OF *CORBICULA FLUMINEA* (MÜLLER) IN TEXAS

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***ABSTRACT*** A database containing 1,234 records of *Corbicula fluminea* in Texas was created based on published literature accounts, survey reports by Texas Parks and Wildlife Department, unpublished records from university and museum collections, personal communications and author's data. This invasive, exotic bivalve was first collected in Texas in the Neches River in 1958 and was next found in El Paso in 1964. Initial presence on opposite sides of the state supports invasion occurring from the west and east. *Corbicula fluminea* has since colonized all major drainage basins in Texas. By 2005, it was known from 162 lotic and 174 lentic waterbodies located in 180 of 257 Texas counties. There was a positive significant correlation between the percentage of invaded waterbodies by reservoir size (Pearson $r^2 = 0.78$) and stream order (Spearman R = 0.65). *Corbicula* populations were found more often in larger reservoirs and higher-order streams and were usually rare to absent in the smallest. Unless precluded by lack of permanent water or inadequate physicochemical parameters, *C. fluminea* may colonize most of Texas streams greater than second order and all but the smallest impoundments.

***KEY WORDS:*** *Corbicula fluminea*, invasive species, Texas, stream order, reservoir size

## INTRODUCTION

Invasive species are currently one of the greatest environmental threats around the world, and the total estimated annual cost of their impact in the United States alone exceeds $125 billion (Pimentel et al. 2000). The Asian clam, *Corbicula fluminea* (Müller), is among the most aggressive freshwater invaders worldwide (Morton 1979, McMahon 1999). Since its introduction, *C. fluminea* has become one of the most important molluscan pest species in the United States (McMahon 1983). Its numerous negative attributes have included living animals and shells that have reduced flow in irrigation canals (Prokopovich & Isom 1969), clogged pipes and heat exchangers at power plants and other raw water users (McMahon 1983), and specimens present in river gravels have even interfered with setting concrete (Sinclair & Isom 1963), to name but a few. The total damage cause by *C. fluminea* for United States industries in 1986 alone was estimated at $1 billion (Isom 1986).

Though native to Southeast Asia, Australia, and Africa, *C. fluminea* has been successfully invading North American freshwaters for over 60 y (reviewed in McMahon 1999). Shell material was found on Vancouver Island, British Columbia, in 1924 (Counts 1981) and it was first found alive in 1938 in the Columbia River, Washington (Burch 1944). Fox (1969) suggested it may have entered North America as early as the mid 1800s; however, McMahon (1983) dismissed such an early introduction as unlikely. It subsequently spread throughout 39 continental states, as well as the District of Columbia and Hawaii (Foster et al. 2000). Northern and central Mexico (Hillis & Mayden 1985), South America (Darrigran 2002), and Europe (Morton 1986) have also been invaded.

In Texas, Metcalf (1966) reported first observing and collecting *C. fluminea* near El Paso in November 1964. However, a specimen now in the Houston Museum of Natural Science was collected in the Neches River in September 1958 and others were taken in El Paso in July 1964, prior to Metcalf's report (Howells et al. 2004). By 1969, it was documented in the Lower Rio Grande Valley and lower Nueces River of South Texas (Murray 1971). Within a decade, it had been found at sites throughout central, eastern, and northcentral Texas (Britton & Murphy 1977, Aldridge & McMahon 1978, Pool & McCullough 1979). Because *C. fluminea* was present in eastern Texas in 1958 and in Louisiana by 1961 (Dundee & Harman 1963), the suggestion by Britton and Morton (1979) that Texas may have been invaded from the east and west is almost certainly correct.

To trace the spread of *Corbicula* in Texas, an electronic database was made containing our own data, other previous databases, all available literature data and personal contact information. This paper used these data to investigate the following:

- Spread through Texas counties;
- Spread into lentic and lotic waterbodies;
- Colonization relative to lake size;
- Colonization relative to stream order.

## MATERIALS AND METHODS

### *Taxonomic Considerations*

Although some authorities have suggested that more than one species of *Corbicula* may be present in Texas (Hillis & Patton 1982), others consider all to be forms of a single species (Britton & Morton 1986). For the purposes of this study, all *Corbicula* in Texas waters have been considered to be *C. fluminea.*

### Corbicula fluminea *Spread Across Texas*

The database created to document and examine the spread of *Corbicula* across Texas included published literature accounts, annual bivalve survey reports produced by Texas Parks and Wildlife Department (TPWD), records from Stephen F. Austin State University (SFASU) personnel, a database obtained from C. M. Mather (University of Science and Arts of Oklahoma, Chickasha) and unpublished records from university and museum collections as well as personal communications with a number of individuals. Published records included: Metcalf (1966), Murray (1971, 1978), Metcalf and Smartt (1972), O'Kane (1976), Britton and Murphy (1977), Aldridge and McMahon (1978), Baker (1978), Britton and

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Morton (1979), Pool and McCullough (1979), Horne and McIntosh (1979), Davis (1980a, Davis 1980b, Davis 1980c), Britton (1982), Campbell and Clark (1982), Fontanier (1982), Hillis and Patton (1982), Howard (1982), McMahon (1982), Counts (1986), McMahon and Williams (1986), Neck (1986, 1987) and Shafer et al. (1992). Data from SFASU were results of field surveys conducted in East Texas in 2003. The TPWD records were presented in Howells (1994, 1995, 1996a, 1996b, 1997a, 1997b, 1998, 1999, 2000, 2001, 2002, 2003 and 2004).

Unpublished records obtained from other TPWD personnel, R. C. Harrel (Lamar University, Beaumont, Texas; pers. comm., who also provided unpublished records from the Sabine River Authority), R. F. McMahon (University of Texas at Arlington; pers. comm.), and T. Gallucci (Kerrville, Texas; pers. comm.). Records from the Texas Christian University collection provided by J. C. Britton, who also reviewed our database; records from the Houston Museum of Natural Science provided by J. B. Wise; C. Flaute and G. T. Watters supplied information on specimens in the Ohio State University Museum collection; A. J. Benson (United States Geological Survey) provided USGS listings; and additional new records obtained by the authors were also included.

The resulting database contains 1,234 records of *C. fluminea* presence in Texas for more than 45 y. This database is biased because collection records usually do not represent comprehensive systematic surveys of Texas waterbodies. Many collection efforts were not directed specifically at *Corbicula*, and, in some cases, it may not have been recorded even when present. However, in the absence of such comprehensive field surveys, this database is the only available current and historical information that sheds light on distribution and spread of *C. fluminea* in Texas and represents a long-term data set useful in predicting the spread of other exotic species.

To estimate the spread of *C. fluminea* in Texas counties and waterbodies, we used power regressions between the cumulative numbers of counties and waterbodies reported to have been colonized each year and time since initial discovery in 1958 (Zar 1996).

#### **Corbicula fluminea** *Colonization Relative to Lake Size*

Texas impoundments (Texas has only one natural lake) were grouped into 8 size categories (<0.10, 0.10–0.49, 0.50–0.99, 1.00–4.99, 5.00–9.99, 10.00–49.99, 50.00–99.99 and ≥100 km$^2$). Total numbers of waterbodies in each group were compared with the number of waterbodies with *C. fluminea* records using the Fisher-Freeman-Halton test (a generalization of the Fishers Exact test for 2 by 2, to $r$ by $c$ contingency table) (Freeman & Halton 1951). Twenty-one waterbodies for which size could not be determined were dropped from the analysis.

#### **Corbicula fluminea** *Colonization Relative to Stream Order*

The presence or absence of *C. fluminea* relative to stream order was examined by sampling 27 lotic waterbodies ranging from first to fifth order (21 streams and 6 rivers) in East Texas in 2003 (rivers were considered fourth order and larger). These were located in Anderson ($n$ = 2), Angelina (4), Cherokee (5), Nacogdoches (11), San Augustine (4) and Smith (1) counties. In each stream, samples were collected along three transects run perpendicular to the direction of flow from the shore zone to a water depth of 2 m. Three, replicate Eckman grab samples (0.0233 m$^2$) were taken from two sites (<1 m and 1–2 m depth) on each transect. Collected materials and specimens were washed through a 550-μm mesh. In addition, a portion of the littoral zone (ca. 300 m) was examined to further aid in confirming presence or absence of *C. fluminea* at each site. At each sampling point, depth, substrate type, water temperature, pH, conductivity, calcium concentration and total dissolved solids were recorded. To further identify correlation between stream order and the presence of *C. fluminea*, data were added from Howells (1994, 1995, 1996a, 1996b, 1997, 1999, 2001).

Data analyses were performed using Statistica software (STATISTICA version 6, StatSoft, Inc. 2001) and StatXact-4 (version 4.0.1, Cytel Software Corp.). Effects were considered statistically significant at $P < 0.05$.

## RESULTS

#### **Corbicula fluminea** *Spread Across Texas*

Since the original observation in the Neches River in 1958 (Howells et al. 2004), *C. fluminea* spread to all major drainages in Texas by the mid- to late-1970s (Fig. 1). By September 2004, the species had been documented in 180 counties. It is likely present in several other counties for which verification is lacking, but where waters are present that could, and probably do, support it.

Cumulative documentation of *C. fluminea* distribution by counties was well described by power regression (97% of variance explained; R = 0.98, $P < 0.001$, Fig. 2). However, not all of the 257 Texas counties will be colonized by *C. fluminea*: 47 some counties probably lack sufficient permanent water to support *Corbicula* and may never be successfully invaded. By September 2004 *C. fluminea* has colonized 162 lotic and 174 lentic waterbodies (336 total). The cumulative curves of colonized waterbodies were well described by power function (R = 0.99, $P < 0.001$, Fig. 3).

#### **Corbicula fluminea** *Colonization Relative to Lake Size*

*Corbicula* was found disproportionally more often in the largest reservoirs (up to 88% >100 km$^2$ had records) while was absent or very rare (2%) in the smallest impoundments <0.50 km$^2$ (Table 1). There was a positive correlation between *C. fluminea* presence and waterbody size (Pearson $r^2$ = 0.78, $P$ = 0.009). Further, the size distribution of reservoirs occupied by *C. fluminea* was significantly different from the size distribution of all Texas reservoirs (Fisher statistic = 176.7, $P < 0.001$, Fisher-Freeman-Halton test).

#### **Corbicula fluminea** *Colonization Relative to Stream Order*

During our survey of 21 streams and 6 rivers in East Texas, we found live *C. fluminea* in 5 rivers (Neches and Angelina rivers; Loco, Alazan and Attoyac bayous), and dead shells in one additional river (Ayish Bayou). *Corbicula* was recorded in 2 streams (Eye and Box Creeks, both third order), and dead shells were found in Sampson Creek. None of the clams were found in streams of lower (first and second) order. A positive correlation between *C. fluminea* presence and stream order was found (Spearman R = 0.42, $P < 0.001$). A stronger correlation (Spearman R = 0.65, $P < 0.0001$) between the *C. fluminea* presence and stream order was found when we used additional data (Howells 1994, 1995, 1996a, 1996b, 1997, 1999, 2001) (Fig. 4). The presence of clams was significantly different in streams of different orders. (Kruskal-Wallis test: H (4, 53) = 23.3; $P$ = 0.0001).

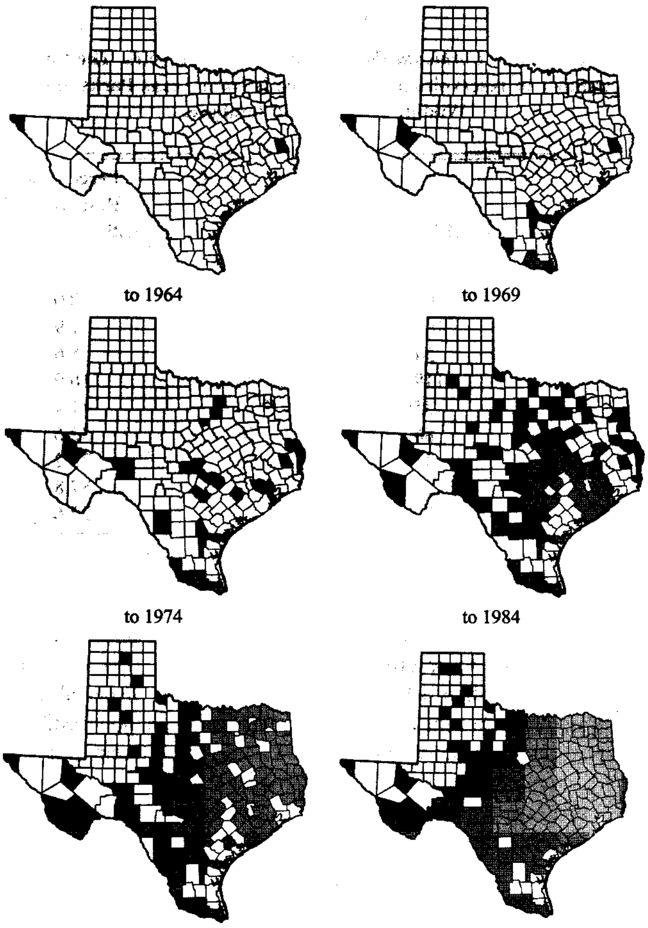


**Figure 1. Records of *Corbicula fluminea* by country (shaded) in Texas from 1958 through 2004 based on data from Metcalf 1966, Murray 1971, 1978, Metcalf and Smartt 1972, O'Kane 1976, Britton and Murphy 1977, Aldridge and McMahon 1978, Baker 1978, Britton and Morton 1979, Horne and McIntosh 1979, Pool and McCullough 1979, Davis 1980a, 1980b, 1980c, Britton 1982, Campbell and Clark 1982, Fontanier 1982, Hillis and Patton 1982, Howard 1982, McMahon 1982, Counts 1986, Neck 1986, 1987, McMahon and Williams 1986, Shafer et al. 1992, Howells 1994, 1995, 1996a, 1996b, 1997a, 1997b, 1998, 1999, 2000, 2001, 2002, 2003, 2004, Howells et al. 2004, Sabine River Authority data, USGS records, OSUM, C. M. Mather database and author's unpublished data.**

## DISCUSSION

### Corbicula fluminea *Spread Across Texas*

After its original discovery in the American Pacific northwest (1938), *C. fluminea* spread to California in 1946, Arizona in 1956 and into Idaho, Nevada and Oregon by 1959 (reviewed in Counts 1986). Invasions into these adjacent states and waters may have been more easily understood than the dramatic range extensions into the Central and Eastern United States. It was documented in Kentucky (1957), Tennessee (1959), Illinois (1960), Florida (1960), Alabama (1961), Louisiana (1961), and Ohio (1962) in the late 1950s and early 1960s (reviewed in Counts 1986). Such rapid, long-distance invasions have largely become typical of the invasion strategy of *C. fluminea*; however, confirmed documentation to explain the mechanism for most such new occurrence is often speculative and usually illusive.

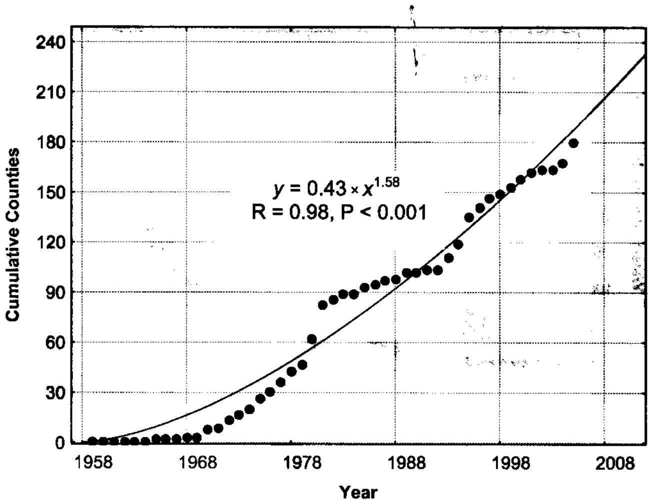


**Figure 2. The dynamic of *Corbicula fluminea* colonization of Texas counties (cumulative number). Power regression between the cumulative number of counties and years since first discovery (1958) with regression equation and coefficient are given.**

The first published report of *C. fluminea* in Texas was that of Metcalf (1966) who found *C. fluminea* near El Paso (Rio Grande drainage) in November 1964. However, specimens in the collection at the Houston Museum of Natural Science indicate that C. E. Boone also collected it there earlier in July 1964 and another had been taken in the Neches River in September 1958 (Fig. 1). By 1969, *C. fluminea* had been documented from Falcon Reservoir in the lower Rio Grande Valley (Murray 1971) and Lake Corpus Christi in the lower Nueces River (Murray 1971, Murray 1978) (Fig. 1); however, subsequent appearances in eastern Texas were not reported until the 1970s. But, by the mid- to late-1970s, *C. fluminea* had been found in all major Texas drainage basins (Britton & Murphy 1977). Not only had the species invaded eastward from west and southwest, but almost certainly also spread westward from the Mississippi River basin of Louisiana (Britton 1982, McMahon 1982) and Neches River of eastern Texas, creating a 2-directional invasion. Relative occurrence of *C. fluminea* in state parks with freshwater subdivided into eastern and western Texas was not different in Neck's survey (Neck 1986) in 1978 to 1983 ($P = 0.25$). Neck (1986) suggested *C. fluminea* was present over most of Texas by the late 1970s, except for the Brazos River system. However, others placed it in the Brazos by the mid 1970s and possibly as early as 1972 or 1973 (Britton & Morton 1979).

Examination of records of *C. fluminea* reports in Texas over time usually fails to show a clear trend in distribution from one geographic location to another; rather, records of *C. fluminea* occurrences created a patchwork pattern across the state (Fig. 1). Direct downstream movement may explain the 1964 collection in the upper Rio Grande followed by discovery at Falcon Reservoir in 1969 (Fig. 1). However, the appearance of *C. fluminea* in the Neches River in 1958 and Lake Corpus Christi in the lower Nueces River basin in 1969 must have required some other method. From 1970 through 1979, *C. fluminea* was documented in the Brazos, Colorado (including Pecan Bayou and the Concho River), Big Cypress Bayou, Sabine, Trinity, Guadalupe (including the Blanco River), San Jacinto systems as well as additional locations in the Central Rio Grande drainage. Order of these occurrences rarely demonstrates obvious patterns.

Survey efforts in the 1970s and 1980s were sporadic and in-

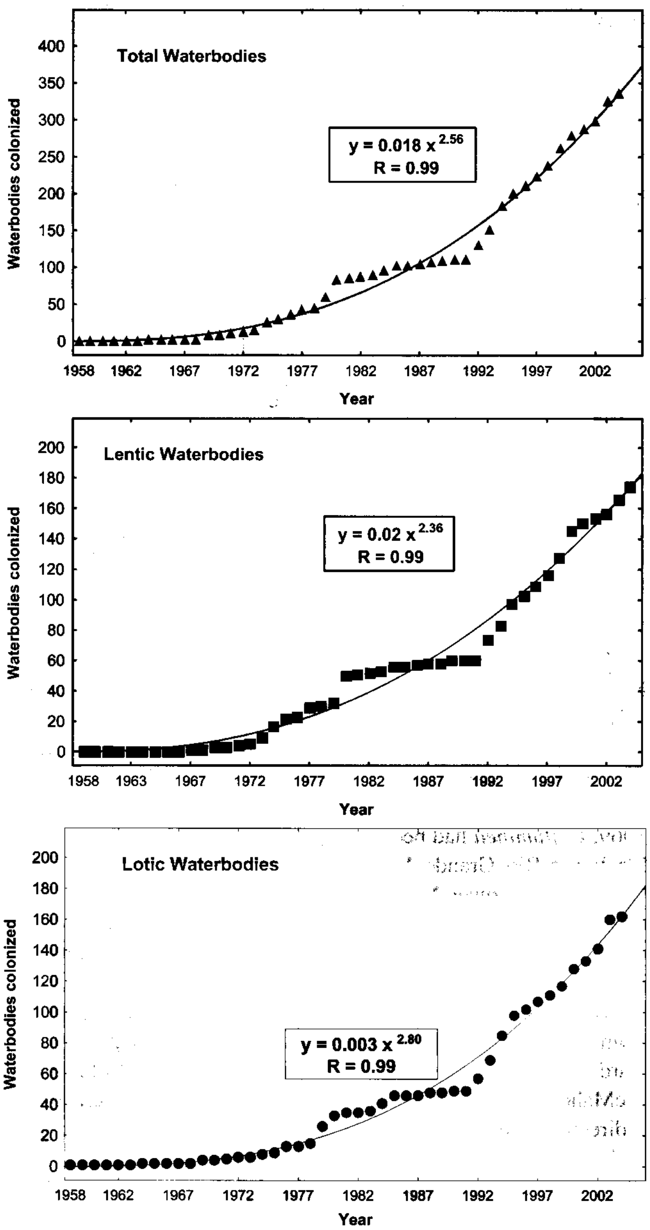


**Figure 3. The dynamic of *Corbicula fluminea* colonization of Texas waterbodies. Cumulative numbers of total waterbodies colonized (top), lentic (middle) and lotic (bottom) waterbodies are given with the equations of power regression between the cumulative number of waterbodies and years since first discovery (1958), and regression coefficients.**

**TABLE 1.**

**Occurrence of *Corbicula fluminea* in Texas reservoirs. The total number of reservoirs and their area is from Texas Parks and Wildlife Department database.**

| Reservoir Area (km$^2$) | Total Number of Reservoirs | Number of Reservoirs with *Corbicula fluminea* | Percent of Reservoirs with *Corbicula fluminea* |
|---|---|---|---|
| < 0.10 | 107 | 0 | 0.0 |
| 0.10–0.49 | 162 | 3 | 1.9 |
| 0.50–0.99 | 54 | 3 | 5.6 |
| 1.00–4.99 | 118 | 20 | 16.9 |
| 5.00–9.99 | 35 | 4 | 11.4 |
| 10.00–49.99 | 86 | 28 | 32.6 |
| 50.00–99.99 | 41 | 30 | 73.2 |
| ≥ 100 | 74 | 65 | 87.8 |
| Total | 677 | 153 | 22.6 |

consistent, and hence, records documenting the presence of *C. fluminea* are also sporadic and inconsistent. Spotty, but almost statewide spread in the 1970s was followed in the 1980s by dramatically increased invasion of adjacent water bodies from most invasion sites. Survey efforts from 1990 through early 2004 confirmed still other populations invading still other available habitats in Texas. Indeed, in Texas, only certain areas of the Panhandle, the northwestern plains, TransPecos and South Texas scrublands, where permanent fresh water is limited or lacking, are likely to be free of *C. fluminea* populations.

McMahon (1983) and others have commented on the "unnatural" range extensions seen during the invasion of *C. fluminea* across North America, including Texas. Howells et al. (1996) called this irregular spread "enigmatic." Even mountain ranges have not proven to be effective barriers to the distribution of *C. fluminea* (McMahon 1983). Passive downstream dispersal with water current (Prezant & Chalermwat 1984, McMahon 1982) as well as upstream active movement (which is different, for example, from only passive natural movement downstream for another aggressive aquatic invader, *Dreissena polymorpha*) are the most probable among natural mechanisms of dispersal. Generally, relocation of *C. fluminea* in fish or waterfowl guts or as juveniles in damp bird feathers or attached to bird's legs are not considered the major vectors of introduction (Thompson & Sparks 1977, Counts 1986, Isom 1986). Numerous sources have suggested the original North American introduction may have been associated with human consumption, a factor that could relate to its further distribution as well. A number of vectors have been associated with the rapid dispersal of *C. fluminea*, most of which relate to deliberate and accidental human activities. McMahon (1983) listed deliberate relocation as a tourist curiosity, accidentally in pleasure boat bilges, in bait buckets and by aquarium hobbyists. Counts

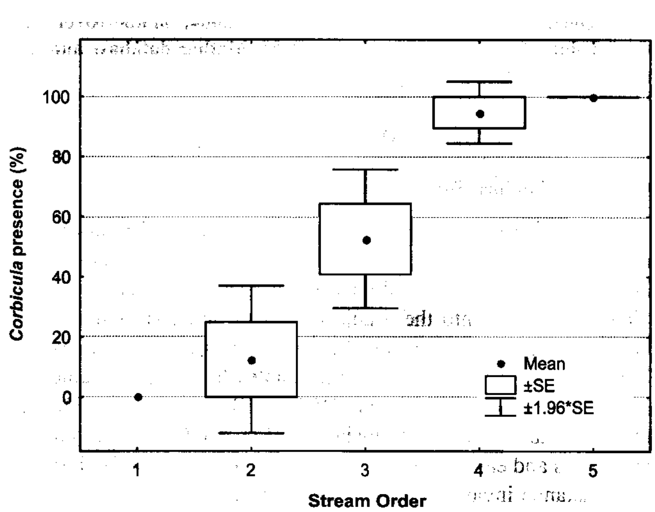


**Figure 4. The presence of *Corbicula fluminea* in Texas relative to stream order for selected waters based on Howells (1994, 1995, 1996a, 1997, 1999, 2001) data.**

(1986) also listed accidental introductions with aquacultural species, Sinclair and Isom (1963) noted transport in sand and gravel mined from riverbeds and Dinges (1976) reported deliberate introduction for water purification purposes.

Definitive methods of *C. fluminea* introduction and distribution in Texas remain ill defined; however, accidental relocation in bait bucket water, pleasure boats, and aquacultural introductions are likely major sources. Many sport and commercial activities have potential for both short- and long distance transport of aquatic invasive species. In Texas, no noteworthy harvest or use for human consumption or for use as bait of *Corbicula* was noted in a 1992 survey (Howells 1993). However, sport fishermen may transport *Corbicula* fouled tackle, nets, traps and other gear from one lake to another. Further, *Corbicula* is believed to have achieved a broad portion of its dispersal in the United States as discarded bait (Ingram et al. 1964, Britton & Morton 1979). Neck (1986) has found that *Corbicula* was more likely (with marginal significance) to be present in Texas parks with fishing activities than ones without such facilities. Although *C. fluminea* has been observed in Texas pet stores and is available from some mail order tropical fish dealers (under the name yellow clam), neither is believed to represent a major source of introduction or distribution in Texas. Likewise, for another invasive mollusk, *Dreissena polymorpha*, Karatayev et al. (2003) found that zebra mussels were more common in Belarusian lakes with government commercial fisheries than those without ($P < 0.001$), and more common in large lakes than small lakes ($0.025 > P > 0.0001$, 3-way G-test). However, larger lakes were much more likely to have an intensive fishery than small lakes ($P < 0.0001$). We should add here that *C. fluminea*, unlike dioecious *Dreissena*, has hermaphroditic reproduction, and therefore they may need fewer specimens to start a population.

Considering all the faults and biases of our database listed earlier, the cumulative *Corbicula* distribution in Texas counties with time was well described by power regression ($R^2 = 0.98$). During the years, since 1958 to 2004, *C. fluminea* colonized in average of 4 counties/year. However, two small peaks of more intensive reporting occurred in 1979 to 1980 (when 15 and 21 counties with *C. fluminea* were added to the database) and again starting in 1994 (16). First peak was associated with the publication of the proceedings of the First International *Corbicula* Symposium (1979). The second peak was due to freshwater mussel survey activity initiated in 1992 by R. G. Howells that also documented *C. fluminea* at many sampling sites. There was also one "flat" period on the cumulative graph in 1980s (probably due to the low research activity). Based on records to date, the 210 Texas counties that have suitable habitats may be colonized by 2008 (Fig. 2) though undocumented populations likely occur in many or all at present.

The rate of *Corbicula* spread was not different in lentic and lotic waters (Fig. 3). Using data from Neck (1986), *C. fluminea* was as likely to be present in both habitat types ($P > 0.40$, $\chi^2$ test).

#### Corbicula fluminea *Colonization Relative to Lake Size*

Our data suggest that large reservoirs will be more often colonized by *C. fluminea* than the small ones. Kraft and Johnson (2000) found a similar association between *D. polymorpha* invasion and larger lakes as well. Because larger water bodies often experience more human activity than smaller ones, they have not only an increased potential for introduction and colonization, but for detection as well. Besides, formal bivalve surveys in Texas often focused on large reservoirs that are important centers of human activity. Therefore, *Corbicula* may be currently present in some small reservoirs where its presence has been unnoticed. However, recent survey of 15 reservoirs with surface area <0.1 $km^2$ did not reveal the presence of *Corbicula* in any of them (Karatayev, Burlakova, pers. observations).

#### Corbicula fluminea *Colonization Relative to Stream Order*

Our data suggest that first order streams are not suitable for *C. fluminea*. However, we did not have a large number of first order streams in our surveys. It is known from literature that mollusk species richness increases with stream size (reviewed in Strayer & Smith 2003). Therefore, *C. fluminea* presence is more likely with increasing stream order. Lesser order streams (first and sometimes second order) may be too small and become intermittent during dry seasons, exposing populations to air and causing them to die (McMahon 1979). Nevertheless, *C. fluminea* are known to be successful in various habitats including small, spring-fed streams (reviewed in McMahon 1999). Presence of *Corbicula* in small unstable waterbodies could be explained by their ability to recolonize waterbodies rapidly after die-offs (McMahon 1999), suggesting a potential for invasion of first order streams as well.

Among other abiotic parameters that may limit the presence of the *C. fluminea* in a waterbody are pH and temperature. *Corbicula fluminea* is known from waterbodies with pH as low as 5.6 (Kat 1982) and temperature limits from 2°C (Mattice 1979, Rodgers et al. 1979) to 36°C to 37°C (Dreier & Tranquilli 1981, Britton & Morton 1982). Almost all Texas waterbodies fit in these limits.

Analysis of more than 40 y of continuous invasion of *C. fluminea* revealed that Texas appears to have been colonized simultaneously both from the east and west. Since initial discovery in 1958, by 2004 *C. fluminea* was reported from 162 lotic and 174 lentic waterbodies located in 180 of the 257 Texas counties. *Corbicula* was present disproportionally more often in the largest waterbodies whereas was absent or very rare in the smallest. There was a positive significant correlation between the percentage of *C. fluminea* presence and the size of reservoirs and between *C. fluminea* presence and stream order. *Corbicula fluminea* may colonize most of Texas streams greater than second order and reservoirs with adequate dissolved oxygen levels and pH.

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