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

ALEXANDER Y. KARATAYEV,1,4 ROBERT G. HOWELLS,2 LYUBOV E. BURLAKOVA1 AND BRIAN D. SEWELL3

1Department of Biology, Stephen F. Austin State University, Nacogdoches, Texas 75962; 2Texas Parks and Wildlife Department, Heart of the Hills Fisheries Science Center, Ingram, Texas 78025; 3Alabama-Coushatta Tribe of Texas, Livingston, Texas 77351

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in Texas was created based on published literature accounts, survey reports by Texas Parks and Wildlife Department, unpublished records from university and museum collections, personal communications and author's data.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 r² = 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 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

*Corresponding author. E-mail akaratayev@sfasu.edu
Corbicula fluminea 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 with 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, 2000, 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 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 disproportionately 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, 2000) (Fig. 4). The presence of clams was significantly different in streams of different orders. (Kruskal-Wallis test: H (4, 53) = 23.3; $P = 0.0001$).
Invasive History of Corbicula in Texas

Invasive History of Corbicula in Texas


d to 1964
to 1969
to 1974
to 1984
to 1994
to 2004


DISCUSSION

Corbicula flavimena Spread Across Texas

After its original discovery in the American Pacific northwest (1938), C. flavimena 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. flavimena; however, confirmed documentation to explain the mechanism for such new occurrence is often speculative and usually illusive.

The first published report of C. flavimena in Texas was that of Metcalf (1966) who found C. flavimena 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. flavimena 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. flavimena 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. flavimena 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. flavimena 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. flavimena reports in Texas over time usually fails to show a clear trend in distribution from one geographic location to another; rather, records of C. flavimena 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. flavimena 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. flavimena 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-
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.

<table>
<thead>
<tr>
<th>Reservoir Area (km²)</th>
<th>Total Number of Reservoirs</th>
<th>Number of Reservoirs with Corbicula fluminea</th>
<th>Percent of Reservoirs with Corbicula fluminea</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 0.10</td>
<td>107</td>
<td>0</td>
<td>0.0</td>
</tr>
<tr>
<td>0.10-0.49</td>
<td>162</td>
<td>3</td>
<td>1.9</td>
</tr>
<tr>
<td>0.50-0.99</td>
<td>54</td>
<td>3</td>
<td>5.6</td>
</tr>
<tr>
<td>1.00-4.99</td>
<td>118</td>
<td>20</td>
<td>16.9</td>
</tr>
<tr>
<td>5.00-9.99</td>
<td>35</td>
<td>4</td>
<td>11.4</td>
</tr>
<tr>
<td>10.00-49.99</td>
<td>86</td>
<td>28</td>
<td>32.6</td>
</tr>
<tr>
<td>50.00-99.99</td>
<td>41</td>
<td>30</td>
<td>73.2</td>
</tr>
<tr>
<td>≥ 100</td>
<td>74</td>
<td>65</td>
<td>87.8</td>
</tr>
<tr>
<td>Total</td>
<td>677</td>
<td>153</td>
<td>22.6</td>
</tr>
</tbody>
</table>

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 & Chalermwatt 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 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...
(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 diocesic 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 (Matice 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 disproportionately 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.

**ACKNOWLEDGMENTS**

The authors thank Tony Gallucci (Kerrville, Texas), David E. Bowles (TPWD, San Marcos, Texas), Mark H. Howell (TPWD, Wichita Falls, Texas), Marsha M. Reimer (TPWD, Austin, Texas), Larry O. Calvin (TPWD, Cooper, Texas), Richard C. Harrel (Lamar University, Beaumont, Texas), Joseph C. Britton (Texas Christian University, Fort Worth, Texas), Robert F. McMahon (University of Texas, Arlington), C. M. Mather (University of Science and Arts of Oklahoma, Chickasha), J. B. Wise (Houston Museum of Natural Science), C. Flateau and G. Thomas Watters (Ohio State University Museum), and A. J. Benson (U.S. Geologic Survey, Gainesville, Florida) for providing data for the analysis. We would like to acknowledge the support provided by Stephen F. Austin State University (Faculty Research Grant # 14123 to AYK, LEB and Dianna K. Padilla, 2003 to 2004). We appreciate the helpful suggestions of the unanimous reviewers.
LITERATURE CITED


Isom, B. G. 1986. Historical Review of Asiatic Clam (Corbicula) Invasion


