

Notes and Discussion Piece

Recent Evaluation of *Corbicula* Form D Distribution in the Midwest, U.S.A.

ABSTRACT.—The genus *Corbicula* contains one of the most common and successful aquatic invasive species to North America. Prior to 2015 two predominant species of *Corbicula* were known from the United States—*C. fluminea* and *C. largillierti*, referred to as Forms A and B, respectively. Form A has spread throughout most of the U.S., while Form B is mainly contained in the Midwest and southern U.S. In 2015 a novel *Corbicula*, known as Form D, was discovered in the Illinois River, at Marseilles, Illinois, and was later reported from the Ohio River. Our primary objective for this study was to report additional records of Form D, with a focus on the upper Illinois River watershed. Surveys during summer 2017 verified the presence of Form D in the Tennessee and Mississippi rivers, as well as multiple new locations in the Des Plaines and Illinois rivers, where all three *Corbicula* forms co-exist.

INTRODUCTION

Members of the genus *Corbicula* are moderately-sized freshwater clams native to the temperate/tropical regions of Asia, Africa, and Australia and have become one of the most common and successful aquatic invasive species to North America (Britton and Morton, 1986). Their colonization success is attributed to a suite of life history characteristics, including high fecundity, rapid maturation, self- and cross-fertilization, and passive and active dispersal capabilities (McMahon, 2002; Sousa *et al.*, 2008). *Corbicula* can produce androgenic clones and essentially acquire eggs of other *Corbicula* forms while ejecting the maternal nuclear DNA (Lee *et al.*, 2005; Pigneur *et al.*, 2012; Pigneur *et al.*, 2014; Tiemann *et al.*, 2017). Furthermore, *Corbicula* can employ functional hermaphroditism; therefore, hypothetically, only one individual is needed to establish a population.

At the time of *Corbicula* colonization in the Midwest during the 1960s, significant declines occurred in native unionid presence and species richness (Williams *et al.*, 1993; Haag, 2012). *Corbicula* has been shown to compete with native mussels for food and space or have other negative effects on glochidia and young juveniles, such as ingesting them and limiting growth rates (Yeager *et al.*, 2000; Hakenkamp *et al.*, 2001; Vaughn and Hakenkamp, 2001; Vaughn and Spooner, 2006; Ferreira-Rodríguez *et al.*, 2016; Ferreira-Rodríguez and Pardo, 2017). *Corbicula* arrived in North America prior to widespread concern about the detrimental effects of invasive species. As a result research on the impact of *Corbicula* on North American unionids has lagged. Studies in other countries with later *Corbicula* invasions have documented detrimental effects on native unionid abundance (Paschoal *et al.*, 2015; references therein). Historically *C. fluminea* (=Form A) was considered to be the only species known throughout the Midwest, but a second *Corbicula* was reported in the early 2000s (*C. largillierti* = Form B; Lee *et al.*, 2005; Tiemann *et al.*, 2017). A third *Corbicula* (Form D) was discovered in Illinois in 2015 and later reported in the Ohio River in 2017 (Tiemann *et al.*, 2017; Tiemann *et al.*, 2018).

Multiple *Corbicula* forms living sympatrically are becoming more prevalent worldwide (see López-Soriano *et al.*, 2018), sparking further research into their sometimes syntopic existence. Although little may be known about *Corbicula* species interactions and their impacts on native unionids, these repeated introductions of *Corbicula* taxa are likely behaving similarly to other classic invasion scenarios resulting in r-selected life history traits being favored (McMahon, 2002). Additionally, Pigneur *et al.* (2014) documented *Corbicula* hybridization, suggesting hybrids could have increased fitness over nonhybrids, but few or no experiments have been conducted to test this hypothesis. Form D continues to be observed throughout the Midwest, often with other *Corbicula* forms. Our objective was to document its distribution in more detail, with a focus on the upper Illinois River watershed.

METHODS

We surveyed 12 sites within the upper Illinois River watershed during the months of June and July 2017 (Table 1, Fig. 1). We conducted visual and tactile surveys along the riverbank, wadeable sandy flats, or at islands to determine if live or dead *Corbicula* were present. At each point along the survey, we excavated with a sieve or net for approximately four person-hours or until 50 live specimens of each

TABLE 1.—Locations sampled in the Illinois River watershed during June and July 2017. Form D records in bold. Specimens were deposited in the Illinois Natural History Survey Mollusk Collection, Champaign, Illinois

INHS catalog no.	Stream	Drainage	State	Species	Live	Dead	Latitude	Longitude	Month	Day	Year
87299	DuPage River	Des Plaines River	Illinois	Form A	10	-	41° 25' 18" N	88° 13' 40" W	July	5	2017
87232	DuPage River	Des Plaines River	Illinois	Form B	3	-	41° 25' 18" N	88° 13' 40" W	July	5	2017
87233	DuPage River	Des Plaines River	Illinois	Form A	-	3	41° 24' 48" N	88° 13' 16" W	July	5	2017
87234	DuPage River	Des Plaines River	Illinois	Form B	1	-	41° 24' 48" N	88° 13' 16" W	July	5	2017
87191	Des Plaines River	Illinois River	Illinois	Form A	2	-	41° 23' 1" N	88° 14' 26" W	July	5	2017
87195	Des Plaines River	Illinois River	Illinois	Form B	13	20	41° 23' 1" N	88° 14' 26" W	July	5	2017
87196	Des Plaines River	Illinois River	Illinois	Form D	102	20	41° 23' 1" N	88° 14' 26" W	July	5	2017
87215	Des Plaines River	Illinois River	Illinois	Form A	44	4	41° 24' 32" N	88° 13' 6" W	July	5	2017
87219	Des Plaines River	Illinois River	Illinois	Form B	12	10	41° 24' 32" N	88° 13' 6" W	July	5	2017
87220	Des Plaines River	Illinois River	Illinois	Form D	17	10	41° 24' 32" N	88° 13' 6" W	July	5	2017
-	Fox River	Illinois River	Illinois	Form A	-	1	41° 21' 30" N	88° 49' 16" W	June	21	2017
-	Fox River	Illinois River	Illinois	-	-	-	41° 20' 58" N	88° 50' 0" W	June	21	2017
87202	Kankakee River	Illinois River	Illinois	Form A	6	-	41° 20' 2" N	88° 11' 4" W	July	5	2017
87280	Kankakee River	Illinois River	Illinois	Form A	103	4	41° 11' 59" N	87° 58' 43" W	July	13	2017
87281	Kankakee River	Illinois River	Illinois	Form B	75	2	41° 11' 59" N	87° 58' 43" W	July	13	2017
87209	Illinois River	Mississippi River	Illinois	Form A	4	3	41° 23' 57" N	88° 17' 9" W	June	22	2017
87212	Illinois River	Mississippi River	Illinois	Form D	11	2	41° 23' 57" N	88° 17' 9" W	June	22	2017
87213	Illinois River	Mississippi River	Illinois	Form B	-	2	41° 23' 57" N	88° 17' 9" W	June	22	2017
87223	Illinois River	Mississippi River	Illinois	Form A	6	-	41° 20' 27" N	88° 49' 52" W	June	21	2017
87224	Illinois River	Mississippi River	Illinois	Form B	-	2	41° 20' 27" N	88° 49' 52" W	June	21	2017
87225	Illinois River	Mississippi River	Illinois	Form D	6	-	41° 20' 27" N	88° 49' 52" W	June	21	2017
87241	Illinois River	Mississippi River	Illinois	Form A	7	7	41° 20' 36" N	88° 50' 24" W	June	21	2017
87242	Illinois River	Mississippi River	Illinois	Form B	1	4	41° 20' 36" N	88° 50' 24" W	June	21	2017
87243	Illinois River	Mississippi River	Illinois	Form D	3	1	41° 20' 36" N	88° 50' 24" W	June	21	2017
87244	Illinois River	Mississippi River	Illinois	Form A	104	13	41° 18' 54" N	88° 41' 27" W	June	22	2017
87245	Illinois River	Mississippi River	Illinois	Form B	15	21	41° 18' 54" N	88° 41' 27" W	June	22	2017
87246	Illinois River	Mississippi River	Illinois	Form D	16	8	41° 18' 54" N	88° 41' 27" W	June	22	2017

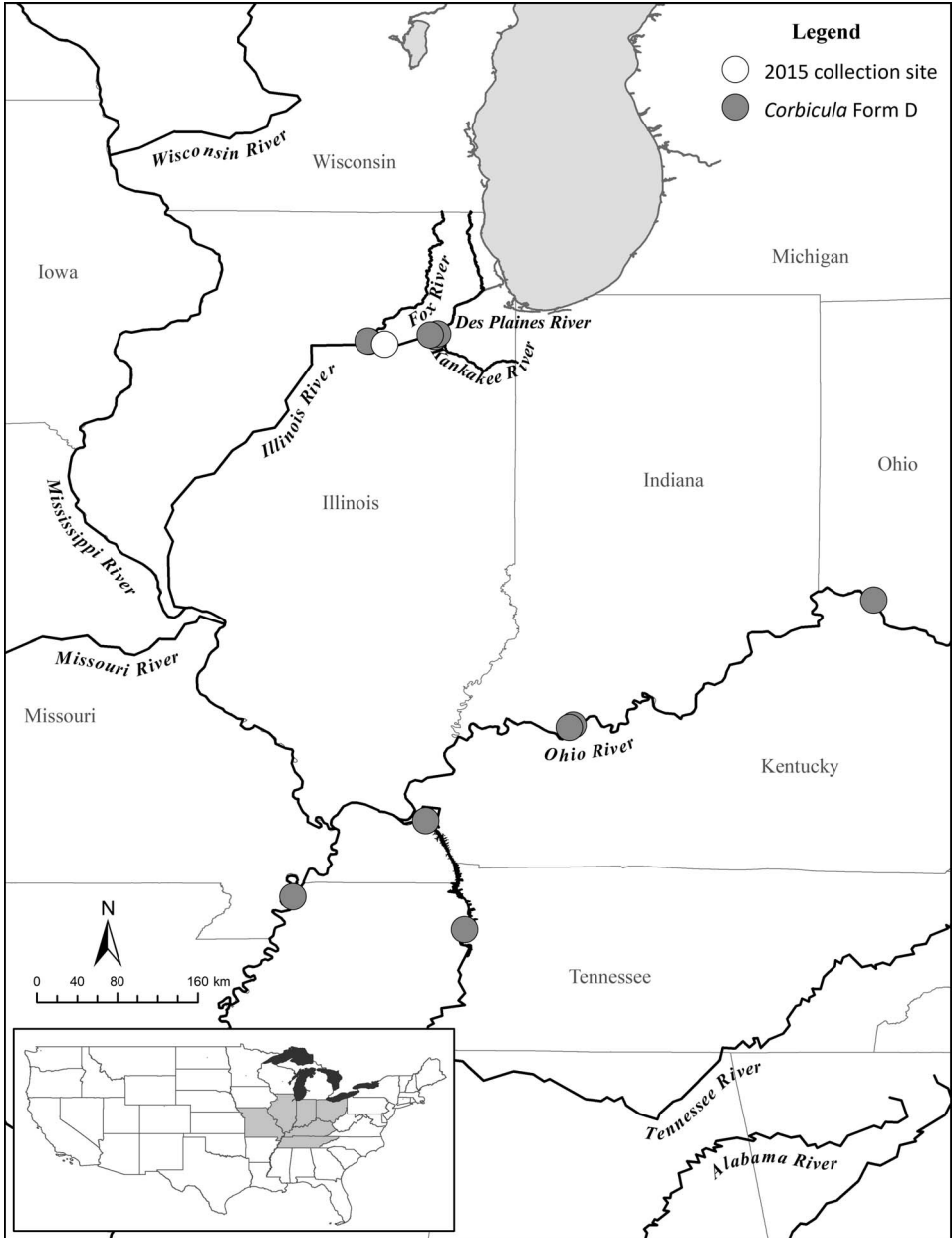


FIG. 1.—In Illinois surveys conducted in 2017 revealed new locations of Form D found approximately 64 river km from the original discovery site at Marseilles, IL (open circle, 2015 collection site) in the Illinois and Des Plaines rivers. Incidental records for Form D include Kentucky Lake, TN; the Tennessee River, KY; the Ohio River, OH, KY; and the Mississippi River, Missouri

TABLE 2.—Locations of Form D incidental encounters from additional watersheds. Specimens were deposited in the Illinois Natural History Survey Mollusk Collection, Champaign, Illinois

INHS catalog no.	Stream	Drainage	State	Species	Live	Dead	Latitude	Longitude	Month	Day	Year
89548	Kentucky Lake	Tennessee River	Tennessee	Form D	-	1	36° 4' 55" N	87° 58' 46" W	October	6	2018
89761	Tennessee River	Ohio River	Kentucky	Form D	3	-	37° 3' 28" N	88° 19' 35" W	August	9	2018
89762	Tennessee River	Ohio River	Kentucky	Form D	1	-	37° 3' 28" N	88° 19' 35" W	July	15	2018
87523	Ohio River	Mississippi River	Kentucky	Form D	1	-	37° 54' 40" N	87° 0' 44" W	October	24	2017
89763	Ohio River	Mississippi River	Kentucky	Form D	1	-	37° 53' 18" N	87° 2' 44" W	July	18	2018
89764	Ohio River	Mississippi River	Ohio	Form D	-	1	39° 1' 35" N	84° 19' 30" W	October	6	2016
88540	Mississippi River	Gulf of Mexico	Missouri	Form D	7	12	36° 22' 37" N	89° 30' 44" W	November	27	2017

species were collected. We also recorded additional specimens encountered incidentally from outside the Illinois River basin that were collected during other surveys in 2017 and 2018 (Table 2). Specimen shells were deposited in the Illinois Natural History Survey Mollusk Collection, Champaign, Illinois. Tissues, if present, were fixed in 95% ethanol and transferred to fresh 95% ethanol to allow for subsequent genetic assessments.

We determined each *Corbicula* form morphologically by shell coloration, ridge structure, and shell shape (see Tiemann *et al.* 2017; Tiemann *et al.*, 2018). Form D specimens have a yellow shell with fine rust-colored rays radiating from the umbo, a creamy white nacre with distinctly purple lateral teeth, and shallower ridging on the external shell. Form B specimens have a dark olive brown shell, tighter but less pronounced shell ridging than Form A, and deeply purple nacre and lateral teeth. Form A has a yellow to yellowish brown shell, numerous pronounced ridges that are evenly spaced, elevated, and concentric. For this form, the nacre is usually white but occasionally has hints of purple. As *Corbicula* age, the shell often darkens, and the different forms become less distinguishable.

RESULTS

Within the upper Illinois River watershed, we captured forms A, B, and D at all Illinois River and Des Plaines River sites; forms A and B in the DuPage and Kankakee rivers; and only Form A in the Fox River (Table 1). Most *Corbicula* were encountered in sandy or silty sand substrates with no or few unionids present. Surveys conducted in 2017 revealed new locations of Form D found approximately 64 river km from the original discovery site at Marseilles, Illinois (Fig. 1). Incidental records for Form D include Kentucky Lake in Tennessee, the Tennessee River in Kentucky, the Ohio River in Ohio and Kentucky, and the Mississippi River in Missouri (Table 2, Fig. 1).

DISCUSSION

Forms B and D are incrementally establishing in Chicago regional streams but do not yet appear to be in Lake Michigan. The northerly dispersal of these two forms, under natural circumstances, is likely to be slow and more constrained due to colder temperature regimes during winter months, but ultimately this temperature shift will not be a limiting factor for eventual establishment (Müller and Baur, 2011; Smith *et al.*, 2018). *Corbicula* can actively and passively (*i.e.*, through flow, fish, anthropogenic activities) disperse both downstream and upstream (Voelz *et al.*, 1998; McMahon, 1999, 2002; Gatlin *et al.*, 2013). Voelz *et al.* (1998) documented active upstream dispersal at approximately 1.2 km/y. In large lakes Minchin and Boelens (2018) reported approximately >5 km dispersal over a period of 6 y. However, dispersal is difficult to measure without standardized monitoring efforts and many researchers do not differentiate *Corbicula* taxa. Therefore, forms B and D are likely much more widespread than previously thought.

In conclusion we have been able to confirm and expand on the reported distribution of Form D. Based on our results and past patterns of invasion, it is likely that Form D will be found in other drainages throughout the Eastern U.S., beyond those sampled in this study. Further monitoring and research are needed to determine the extent of establishment of *Corbicula* and the implications its presence may have for native fauna. Future studies on competition and the reproductive habits (such as hybridization) of the different forms in sympatry (Pfenninger *et al.*, 2002) should be undertaken to reveal the potential impacts these processes have on the persistence and further spread of this invasive group.

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