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Nonindigenous aquatic mollusks in Illinois

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Research Article

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Abstract

Nonindigenous aquatic species (NAS), some of which are referred to as aquatic invasive species (AIS) or non-native aquatic species, are those aquatic organisms that have become established beyond their native ranges. They often inhabit a variety of habitats and physicochemical conditions, reach high densities, and alter ecosystem function. Understanding the distribution of nonindigenous aquatic species is vital to protecting native biodiversity in invaded ecosystems. A search of museum collections, literature accounts, and field surveys conducted in recent years by biologists from the Illinois Natural History Survey, Illinois Department of Natural Resources, and other agencies revealed 13 nonindigenous aquatic mollusk species reported to occur in Illinois. Ten species (five bivalves and five gastropods) have viable reproducing populations. One species, the Big-eared Radix *Radix auricularia* (Linnaeus, 1758), is no longer extant in Illinois, and two species, the European Stream Valvata *Valvata piscinalis* (Müller, 1774) and European Fingernail Clam *Sphaerium corneum* (Linnaeus, 1758), have an unknown status. Some species, such as the Basket Clam *Corbicula fluminea* (Müller, 1774), Zebra Mussel *Dreissena polymorpha* (Pallas, 1771), and Chinese Mysterysnail *Cipangopaludina chinensis* (Gray in Griffith and Pidgeon, 1833), are widespread and abundant. However, other species like the Mottled Fingernail Clam *Eupera cubensis* (Prime, 1865) and New Zealand Mudsnail *Potamopyrgus antipodarum* (Gray, 1843) are currently restricted to a particular location or drainage. Other nonindigenous aquatic mollusks with the potential for becoming established in Illinois or border waters are also discussed.

Introduction

Nonindigenous, or non-native, aquatic species are those aquatic organisms that become established beyond their native ranges and are referenced as “NAS” by the U.S. Geological Survey (USGS) database (https://nas.er.usgs.gov/) and others (i.e., O’Malia et al. 2018). Nonindigenous aquatic species can cause profound disturbances that affect aquatic ecosystems in a myriad of ways (Strayer et al. 2006; Mainka and Howard 2010). These species are also termed aquatic invasive species (AIS) if the species spreads prolifically and/or overpopulates an area. The ecological and economic effects caused by nonindigenous aquatic mollusks are extensive (Pimentel et al. 2005; Rixon et al. 2005; Keller et al. 2008) and rival that of climate change (Mainka and Howard 2010; Diez et al. 2012; Bellard et al. 2013; Gama et al. 2017). Nonindigenous aquatic mollusks can act as ecosystem engineers that alter the physical state of the environment and shift resource availability, which can cause cascading effects on the aquatic ecosystems and negatively affect native species (Cuddington and Hastings 2004; Emery-Butcher et al. 2020). Species such as the Basket Clam *Corbicula fluminea* (Müller, 1774) and Zebra Mussel *Dreissena polymorpha* (Pallas, 1771) can not only affect water clarity, which changes benthic production and alters nutrient cycling, but can also outcompete native species in the invaded ecosystem (Stewart and Haynes 1994; Lougheed et al. 1998; Darrigran 2002; Strayer et al. 2006). Lastly, some species, especially aquatic snails, can host parasites that affect wildlife, livestock, and human health (Chung and Jung 1999; Bachtel et al. 2019; Preston et al. 2022).

Nonindigenous aquatic mollusks can be introduced in a variety of ways, including intentional (e.g., deliberate) and unintentional means (e.g., release of organisms without intention of creating established populations) (Mills et al. 1993; Preston et al. 2022). Species such as *D. polymorpha* and the New Zealand Mudsnail *Potamopyrgus antipodarum* (Gray, 1843) have been introduced through the release of ballast waters of transoceanic ships, whereas others, such as *C. fluminea* and the Chinese Mysterysnail *Cipangopaludina chinensis* (Gray in Griffith and Pidgeon, 1833), have been introduced through human-mediated means like importation for food markets (Mills et al. 1993). Most nonindigenous aquatic mollusks have several traits that aid in their spread after introduction. For example, *Corbicula* spp. and *Dreissena* spp. grow rapidly, mature at an early life stage, and have high fecundity, thus allowing for precipitous population expansions after being introduced in new areas (McMahon 2002). Nonindigenous aquatic mollusks can then disperse via natural vectors, including hydrochory (fluvial currents) and zoochory (other animals), or through human-mediated activities, such as recreational boating and commercial vessels, bait bucket and aquarium releases, and live food markets (Rixon et al. 2005; Belz et al. 2012; Kappes and Haase 2012; Karatayev et al. 2015; Coughlan et al. 2017; Rodríguez-Rey et al. 2021; Preston et al. 2022). Once established, nonindigenous aquatic mollusk populations are notoriously difficult to control and nearly impossible to eradicate (Pimentel et al. 2005; Keller et al. 2007; Coughlan et al. 2018; Coughlan et al. 2019). Opportunities for new introductions of nonindigenous aquatic species exists through complex global shipping routes and navigable waterways, and the effects from these introductions are compounded by the unrelenting consequences of climate change (O’Malia et al. 2018; Smith et al. 2018; Gervais et al. 2020; Saebi et al. 2020). Hence, preventing new introductions is critical to minimizing these perils. As biological invasions continue unabated throughout the world (Mack et al. 2000; Mainka and Howard 2010), understanding the effects of nonindigenous aquatic mollusks is essential to conserving and restoring the native fauna in invaded ecosystems (Strayer et al. 2006; Simberloff et al. 2013).

Managing nonindigenous aquatic mollusks requires information about their distributions and identification of which systems are susceptible to invasion. However, little is known about the distribution and status of several nonindigenous aquatic mollusk species. Compiling baseline information, such as species distributions, is a critical first step to studying the effects of nonindigenous aquatic mollusks on the native aquatic mollusk fauna. Cummings (1991) listed four nonindigenous aquatic mollusk species as occurring in Illinois, and Jacobs and Keller (2017) reported six species established within Illinois inland waters and three others as “discovered but not established” within the state. We have identified 13 nonindigenous aquatic mollusk species with historic or current populations in Illinois. The purpose of this review is to summarize the known locations of each nonindigenous aquatic mollusk species in Illinois, thereby establishing baseline data for future comparison. We also provide basic life-history information about the known nonindigenous aquatic mollusks in Illinois, as well as identifying features of these species.

Methods

We queried or visited multiple sources to gather all known records for nonindigenous aquatic mollusks in Illinois. Museum collection holdings came from the Academy of Natural Sciences of Drexel University, Philadelphia; Auburn University Museum of Natural History, Auburn, Alabama; Bell Museum, St. Paul, Minnesota; Carnegie Museum of Natural History, Pittsburgh; Chicago Academy of Sciences; Delaware Museum of Natural History, Wilmington; Field Museum of Natural History, Chicago; Florida Museum of Natural History, Gainesville; Illinois Natural History Survey, Champaign; Illinois State Museum, Springfield; Mississippi Museum of Natural Science, Jackson; National Museum of Natural History, Smithsonian Institution, Washington, DC; North Carolina Museum of Natural Sciences, Raleigh; Ohio State University Museum of Zoology, Columbus; University of Michigan Museum of Zoology, Ann Arbor; and University of Wisconsin Zoological Museum, Madison. We did not examine all museum records in person but requested photographs of those records we thought might be of outliers, based upon distributional data, and omitted those erroneous records from our consideration.

We also examined literature accounts (e.g., Baker 1902;

Cummings 1991; Grigorovich et al. 2005; Grigorovich et al. 2008; Sneen et al. 2009; Jacobs and Keller 2017; Tiemann et al. 2017) for additional records not captured through museum holdings. We queried publicly available databases: the USGS' Nonindigenous Aquatic Species program (https://nas.er.usgs.gov/) and the U.S. National Science Foundation (NSF), in part, funded InvertEBase [InvertEBase Portal Home (invertebase.org)]. Both compile data from multiple sources and could overlap museum holdings or other available databases. We also included field survey data of nonindigenous aquatic species encounters documented by colleagues within the Illinois Natural History Survey (INHS), Illinois Department of Natural Resources (IDNR), U.S. Fish and Wildlife Service, county forest preserve districts, and other natural resource agencies. Lastly, we examined the role and utility of citizen-science data to document occurrences of nonindigenous aquatic mollusk species. We queried iNaturalist (www.inaturalist.org) for all available nonindigenous freshwater mollusk data for Illinois; iNaturalist is a joint initiative between the California Academy of Sciences and the National Geographic Society. We only included results from this query that had a clear image of the specimen record and a user-provided basic level of identification (e.g., *Corbicula*). We verified each record for correct identification to the species level, if possible, from the image or images provided. We also excluded nonplottable occurrence records from our database, such as those with unclear or imprecise locality descriptions. The data we considered valid were archived in the Illinois Data Bank (https://databank.illinois.edu) and are available for future studies.

We used the occurrence records to create maps of all known nonindigenous aquatic mollusk species in Illinois, including the border waters of Lake Michigan and the Mississippi, Ohio, and Wabash rivers. All maps were created using ArcMap GIS software (version 10.5.1, Esri Inc.). The maps included occurrence records described above, a streams layer (obtained from the IDNR), an Illinois county layer (obtained from the Illinois Geospatial Data Clearinghouse, which the Illinois State Geological Survey hosts), and a Lake Michigan layer (obtained from the USGS Great Lakes Restoration Initiative ScienceBase-Catalog).

Results and Discussion

We gathered 3,638 records from natural history museums, online databases, literature reviews, field surveys, and personal communications, which reveal that 13 nonindigenous aquatic mollusk species have been recorded from Illinois and border waters (Table 1). Ten of the 13 species have reproducing populations, based upon the continued collection of both adults and juveniles. One species, the Big-eared Radix *Radix auricularia* (Linnaeus, 1758), is no longer extant in Illinois, and two species, the European Stream Valvata *Valvata piscinalis* (Müller, 1774) and European Fingernail Clam *Sphaerium corneum* (Linnaeus, 1758), have an unknown status. The earliest records of nonindigenous aquatic mollusks in Illinois are the Faucet Snail *Bithynia tentaculata* (Linnaeus, 1758) and *R. auricularia*, both of which were discovered before 1900 (Baker 1902; Mills et al. 1993). Conversely, Quagga Mussel *Dreissena rostriformis bugensis* Andrusov, 1897, Mottled Fingernail Clam *Eupera cubensis* (Prime, 1865), *P. antipodarum*, *V. piscinalis*, and one *Corbicula* species, were first documented in Illinois after 2000 (Grigorovich et al. 2005; Sneen et al. 2009; Tiemann et al. 2017).

The known modes of introduction for these 13 species of nonindigenous aquatic mollusk species include aquarium releases, ballast-water discharge, and contamination on greenhouse plants (see Table 1). In Illinois, drainage alterations from human development increased transfer rates of various nonindigenous aquatic species in certain areas. For example, the Chicago Area Waterway System (CAWS), an artificial waterway system located in the greater Chicagoland area, has created an unnatural connection between the Mississippi River drainage to the Laurentian Great Lakes basin and allows unabated spread of nonindigenous animals. Species such as *D. polymorpha*, Round Goby *Neogobius melanostomus* (Pallas, 1814), and Eastern Banded Killifish *Fundulus diaphanus diaphanus* (LeSueur, 1817), have spread from Lake Michigan, through the CAWS, and into the Illinois River–Mississippi River drainage (Mills et al. 1993; Pegg 2002; Irons et al. 2006; Willink et al. 2018). Other species, such as *Corbicula* spp., Bighead Carp *Hypophthalmichthys nobilis* (Richardson, 1845), Silver Carp *Hypophthalmichthys molitrix* (Valenciennes, 1844), and Black Carp *Mylopharyngodon piceus* (Richardson, 1845), have dispersed up the Mississippi River and threaten the Laurentian Great Lakes (Laird and Page 1996; Irons et al. 2009; Douglass et al. 2020). Lastly, species such as *C. chinensis* appear to have had multiple introduction points into Illinois (Mills et al. 1993) and are likely from multiple aquaria releases or accidental and/or unintentional introductions (e.g., food-trade escapees).

Lastly, we included iNaturalist data as an exercise to investigate the utility of citizen-science data and believe these types of sources are a valuable tool to document occurrences of nonindigenous aquatic species. Approximately 10% of the records from iNaturalist were misidentified by the community, and we corrected these data for inclusion in this manuscript. We used iNaturalist data, albeit a smaller sample size, that were more accurate than those of previous studies (i.e., Barbato et al. 2021). Regardless, these data provide evidence that citizen-science sources need to be vetted by the scientific community. We experienced similar issues previously reported for iNaturalist and/or citizen-science data (i.e., Barbato et al. 2021), including low quality of photographs, bias in favor of larger or more common species, and poor taxonomic knowledge resulting in misidentifications.

Species accounts of nonindigenous aquatic mollusk species reported in Illinois

BIVALVIA: CYRENIDAE—*Corbicula* spp., including *Corbicula fluminea* (Müller, 1774) (Figure 1)

TABLE 1 Nonindigenous aquatic mollusks reported from Illinois waters, first known occurrence 1871–2015, and the presumed mode of introduction.

CLASS, FAMILY	SCIENTIFIC NAME	COMMON NAME	INTRODUCTION		CITATION
			YEAR	MODE	
BIVALVIA					
CYRENIDAE	Form A (= *Corbicula fluminea*)	Basket Clam	1957	unknown	Stein 1962; Mills et al. 1993
	Form B (= *Corbicula largillierti*)	Basket Clam	1987	unknown	INHS 3987
	Form D (= *Corbicula* sp.)	Basket Clam	2015	unknown	Tiemann et al. 2015
DREISSENIDAE	*Dreissena polymorpha*	Zebra Mussel	1989	ballast, then dispersal	Mills et al. 1993; Jacobs and Keller 2017
	Dreissena rostriformis bugensis	Quagga Mussel	2002	ballast, then dispersal	USGS 263229; Mills et al. 1993
SPHAERIIDAE	*Eupera cubensis*	Mottled Fingernail Clam	2006	ballast	Sneen et al. 2009
	Sphaerium corneum	European Fingernail Clam	1958	unknown but likely ballast, then dispersal	FMNH 108062; Mills et al. 1993; Grigorovich et al. 2003
GASTROPODA					
BITHYNIIDAE	*Bithynia tentaculata*	Faucet Snail or Mud Bithynia	1871	ballast	Baker 1902; Mills et al. 1993
HYDROBIIDAE	*Potamopyrgus antipodarum*	New Zealand Mudsnail	2006	ballast, then dispersal	USGS 252814; Zaranko et al. 1997
LYMNAEIDAE	*Radix auricularia**	Big-eared Radix	1901	greenhouse plants	Baker 1901
VALVATIDAE	*Valvata piscinalis*	European Stream Valvata	2002	ballast, then dispersal	Mills et al. 1993; Grigor-ovich et al. 2005
VIVIPARIDAE	*Cipangopaludina chinensis*	Chinese Mysterysnail	1938	aquarium	Haas 1939
	Heterogen japonica	Japanese Mysterysnail	1995	aquarium	INHS 18102; Mills et al. 1993

Note: * indicates species that is no longer extant in Illinois waters.

Corbicula is by far the largest and most well-known genus in the Family Cyrenidae, with a current morphology-based estimate of 60–70 living species (Huber 2015; Bieler and Mikkelsen 2019). *Corbicula* species have been introduced around the world, including Illinois. There are no universally accepted common names for the genus, but they have been previously referenced as Asian Clams, Basket Clams, Golden Orbs, or other local colloquial names; however, we refer to them here as simply *Corbicula*. *Corbicula* are native to the temperate and tropical regions of Asia and Africa and were first documented in North America as empty shells in British Columbia, Canada, in 1924 (Counts 1981; Morton 1986; Graf 2013). The first living population in North America was discovered in 1938 near the mouth of the Columbia River, separating Washington and Oregon (McMahon 1982). While *Corbicula* was expanding its range along the Pacific Slope of the United States in the 1930s into the 1950s, a secondary introduction was discovered east of the Rocky Mountains in 1957 near the mouth of the Ohio River, separating Illinois and Kentucky (Stein 1962; McMahon 1982). This secondary introduction allowed *Corbicula* to breach the Continental Divide and expand across the eastern United States, including Gulf of Mexico and Atlantic Slope drainages (Parmalee 1965; McMahon 1982). Since then, *Corbicula* have spread throughout North and South America, likely the result of both additional introductions and natural dispersal, and they now range from the Laurentian Great Lakes to the Patagonia region of South America (Beasley et al. 2003; Lee et al. 2005).

Corbicula species have been described as “hyperinvasive” with substantial biofouling capabilities, particularly impacting power plant and industrial water systems (Isom 1986; Morton

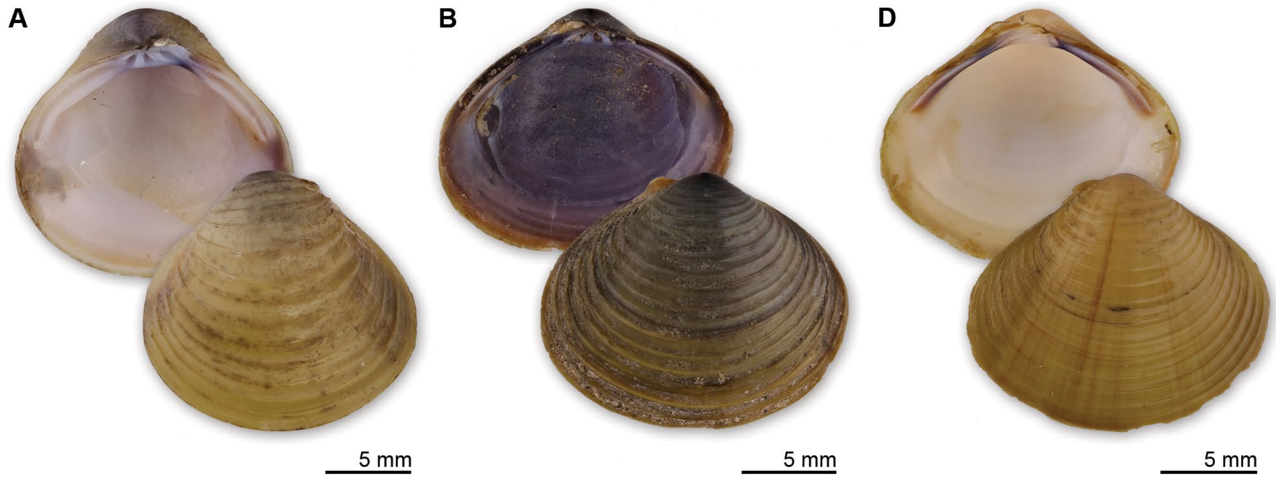

FIGURE 1 *Corbicula* spp.: Form A (left), Form B (center), and Form D (right). Figure modified from that published in Tiemann et al. (2017).

1986). *Corbicula* have caused millions of dollars in damage to industry and infrastructure, and removal costs are estimated at one billion dollars annually (Pimentel et al. 2005). Because of their high abundances, *Corbicula* serve an important role in biofiltration (McDowall and Byers 2018). As a result, *Corbicula* can compete with native species for limited resources, interfere or disrupt the reproductive cycle of native bivalve species by ingesting sperm or glochidia, serve as a vector in disease transmission, and alter benthic substrates (Clarke 1988; Hakenkamp and Palmer 1999; Strayer 1999; Yeager et al. 2000; Hakenkamp et al. 2001; Ferreira-Rodríguez and Pardo 2017; Ferreira-Rodríguez et al. 2018; Haag 2019; Haag et al. 2021).

The systematics and taxonomy of *Corbicula* are muddled and unclear, as is the number of species that have become established in North America (Sinclair 1971; Hillis and Patton 1982; Britton and Morton 1986). The uncertainty stems from the fact that *Corbicula* can be androgenic and hermaphroditic and are capable of hybridizing with sibling *Corbicula* taxa (Konishi et al. 1998; Qiu et al. 2001; Ishibashi et al. 2003; Hedtke et al. 2008; Komaru et al. 2012). This unique reproductive strategy often results in conflicting mitochondrial and nuclear ribosomal DNA sequence data, which hinders taxonomic assessment (Lee et al. 2005; Tiemann et al. 2017; Haponski and Ó Foighil 2019). To attempt to address these conflicting genetic data, Lee et al. (2005) suggested the word Forms or Operational Taxonomic Units, as opposed to using scientific names. They stated three Forms exist in the New World at that time: Form A, which was traditionally named *Corbicula fluminea*; Form B occurring in the United States, sometimes referred to as *Corbicula largillierti* (Philippi, 1844); and Form C occurring in South America. The use of Forms continued after the discovery of another *Corbicula* taxon—Form D—in the United States (Tiemann et al. 2017; Haponski and Ó Foighil 2019; Douglass et al. 2020), as well as additional taxa in Europe (Pigneur et al. 2014; Bespalaya et al. 2018; Sheehan et al. 2019). The Midwest, including Illinois, was long recognized as having a single species of *Corbicula*—*Corbicula fluminea* (Cummings 1991; Cummings and Mayer 1992) or Form A. However, Form B was collected in the Ohio River in Pulaski County as early as 1987 (INHS 3987), and Form D was discovered in the Illinois River in La Salle County as early as 2015 (Tiemann et al. 2017). All three taxa can occur synoptically (Figure 2).

Together, *Corbicula* have been collected in 97 of the 102 counties in Illinois and represent the most widespread and common nonindigenous aquatic mollusk group in Illinois. Form A has been collected in 95 counties, Form B in 16 counties, and Form D in 3 counties (Figure 2). It is unknown how these three taxa were introduced into Illinois. *Corbicula* are transported via fluvial currents, endozoochory (e.g., intestinal passage from waterfowl and fishes), ecozoochory (e.g., byssal attachment to birds and mammals), and human-mediated activities, which include dumping of ballast water, dredging materials, bait buckets, and aquaria releases (Voelz et al. 1998; McMahon 2000; Sousa et al. 2008; Pernecker et al. 2021), although some have questioned whether zoochory is a viable dispersal method (Thompson and Sparks 1977a; Coughlan et al. 2017; but see Minchin and Boelens 2018). Forms B and D are currently restricted to navigable rivers or the mouths of their tributaries in Illinois (Tiemann et al. 2018; Douglass et al. 2020), whereas Form A occurs statewide in large and small waterbodies, including farm ponds and borrow pits (i.e., large pits excavated during construction projects). Form A colonized navigable rivers (e.g., Ohio, Mississippi, and Illinois rivers) and then spread into their tributaries (Fechtner 1962; Stein 1962; Thomerson and Myer 1970; Thompson and Sparks 1977b). The only drainage in Illinois where *Corbicula* are not common is the Rock River drainage; however, populations of Form A were discovered alive in the headwaters of the Kishwaukee River in DeKalb County in 2017, and Form B was discovered in the lower stretches of the Rock River in Whiteside and Lee counties in 2021.

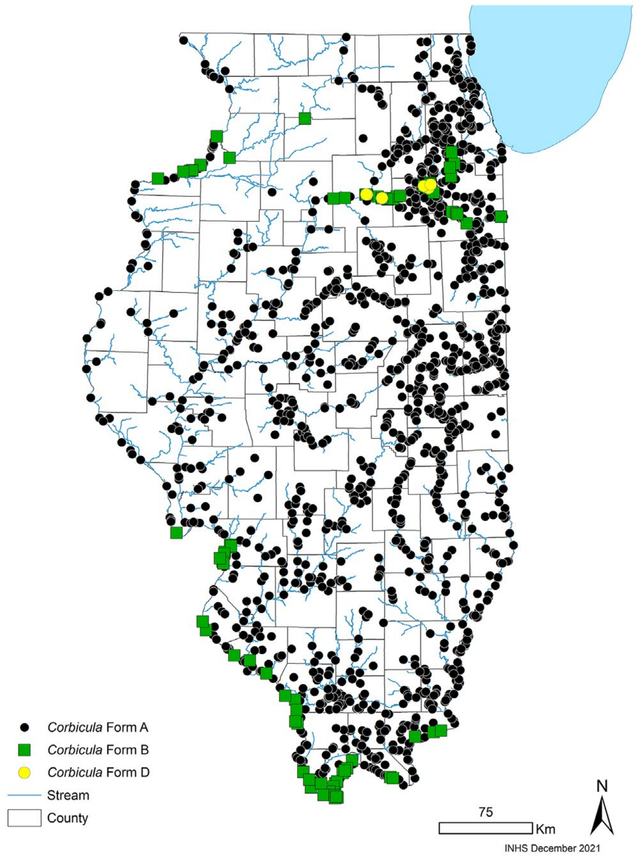

FIGURE 2 Distributions of *Corbicula* spp. in Illinois.

The extent and dispersal rate of Forms A, B, and D are not fully understood (Crespo et al. 2015; Gama et al. 2016; Haag 2019; Pernecker et al. 2021). Form A is often found in small headwater streams, yet their nonparasitic planktonic larvae are not dependent on fishes for reproduction or passive upstream dispersal (Xu et al. 1987; Nichols and Black 1994; McMahon 2002). *Corbicula* are capable of active, unassisted upstream dispersal via pedal movement on a very small scale (< 100 cm in a 2-day period; Pernecker et al. 2021). We assume that zoochory is a viable upstream dispersal mechanism and aids in starting founder populations. Endozoochory seems plausible when considering > 20% of *Corbicula* individuals consumed can survive the gut passage through the digestive system of a fish (Gatlin et al. 2013), the hermaphroditic nature of *Corbicula*, and the possible generation by a female *Corbicula* of > 60,000 pediveliger larvae in a year (Pernecker et al. 2021). Several fishes, such as Common Carp *Cyprinus carpio* (Linnaeus, 1758), are known to consume *Corbicula* and can range > 3 km / year (Butler and Wahl 2010). Lastly, Forms B and D could be underrepresented because some specimens were misidentified prior to their recognition in Illinois (i.e., Tiemann et al. 2017). For example, Form D has been collected in the Illinois River (Tiemann et al. 2017), as well as in the Ohio River in Indiana and Ohio (Tiemann et al. 2018; Douglass et al. 2020). Therefore, Form D is possibly contiguous between these two populations and present in the western (e.g., Mississippi River) and southern (e.g., Ohio River) portions of Illinois.

Distinguishing characteristics (Figure 1). *Corbicula* can be distinguished by their numerous, evenly spaced, concentric, elevated ridges on the shell, and the presence of two sets of lateral teeth. Morphometrically, small (< 25 mm) *Corbicula* spp. can be distinguished from one another via nacre color. Form A has a white nacre with purple highlight and tan-yellowish periostracum with high, widely spaced external ridges, Form B has a deep-purple nacre and olive periostracum with compressed external ridges, and Form D has a white nacre with purple teeth and faint rust-colored rays on the periostracum and external ridges that are not as pronounced as the other *Corbicula* taxa reported from North America.

BIVALVIA: DREISSENIDAE — Zebra Mussel *Dreissena polymorpha* (Pallas, 1771) and Quagga Mussel *Dreissena rostriformis bugensis* Andrusov, 1897 (Figure 3)

Dreissenids, which are native to Eurasia, have become established in riverine and lacustrine environments globally. They are among the most notorious nonindigenous aquatic taxa due to their tremendous biofouling and filtering capabilities (Mills et al. 1993; Marshall and Stepien 2019), and their deleterious ecological and economic effects have been well documented (e.g., Stewart and Haynes 1994; Ricciardi et al. 1998; Strayer 2010). In fact, Jacobs and Keller (2017) scored *D. polymorpha* among the most serious threats to aquatic ecosystems. Dreissenids are the quintessential ecosystem engineers, as they cause changes in nutrient cycling, transform the benthos, shift freshwater food-web dynamics, and alleviate competitive interactions among other invasive species (Higgins and Vander Zanden 2010; Cuhel and Aguilar 2013; Sousa et al. 2014; Crane et al. 2020). Dreissenids can encase freshwater mollusks (both bivalves and snails), which causes significant physiological stress that can essentially suffocate native species (Cummings and Mayer 1992; Tiemann and Cummings 2010). Both *D. polymorpha* and *D. rostriformis bugensis* can fundamentally alter abiotic and biotic interactions, thereby causing severe detrimental ecological and economic effects on native assemblages and ecosystems (Pimentel et al. 2005; Strayer et al. 2006; Higgins and Vander Zander 2010; Karatayev et al. 2015).

For the past 200 years, dreissenids have spread throughout Europe via shipping and artificial canal systems (van der Velde et al. 2010; Zhulidov et al. 2010). In the mid-1980s, *D. polymorpha* and *D. rostriformis bugensis* were transported to the Laurentian Great Lakes in ballast water and subsequently dispersed throughout the Great Lakes, including into Lake Michigan, by the late 1980s (Mills et al. 1993; Jacobs and Keller 2017). *Dreissena polymorpha* first was reported in Illinois in 1989 (Jacobs and Keller 2017), whereas *D. rostriformis bugensis* was first documented in the state in 2002 (USGS 263229). Dreissenids have since been transported widely across the United States via trailered boats and commercial vessels, as well as through natural dispersal mechanisms (Keevin et al. 1992; Schneider et al. 1998; Pegg 2002; Bossenbroek et al. 2007; Rodríguez-Rey et al. 2021). Rec-

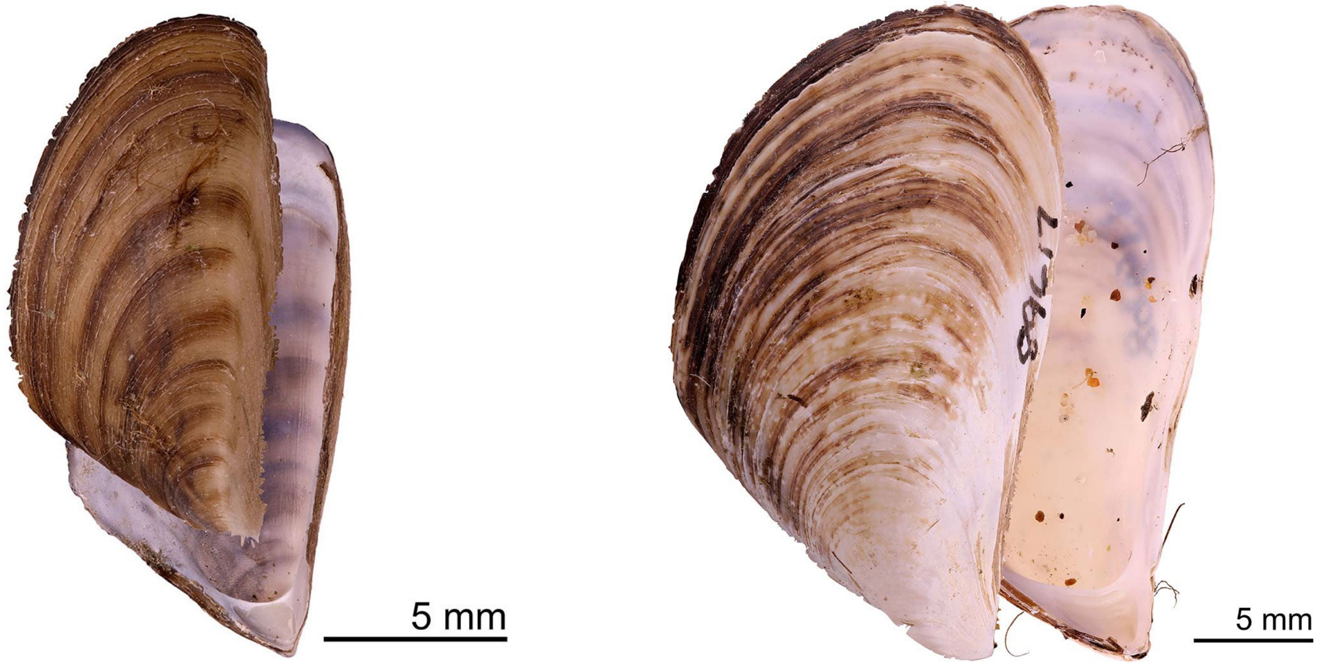

FIGURE 3 Zebra Mussel *Dreissena polymorpha* (left) and Quagga Mussel *Dreissena rostriformis bugensis* (right).

reational users, such as kayakers, canoeists, SCUBA divers, and anglers, are unequivocally responsible for augmenting the spread of dreissenids (e.g., Strayer 2009), as *D. polymorpha* has become established in 47 Illinois counties in isolated borrow pits, farm ponds, kettle lakes, and small (third and fourth order) kayaking streams and navigable rivers throughout Illinois (Figure 4). Because they can survive the gut passage of fishes, dreissenids could also spread through migratory or stocked fishes (Gatlin et al. 2013).

We found records of *D. rostriformis bugensis* from five counties in Illinois (Figure 4). Although reported as not established in inland waters of Illinois (Jacobs and Keller 2017), we believe *D. rostriformis bugensis* is underrepresented in our study and might be established in navigable waterways like the Illinois, Mississippi, and Ohio rivers (see Grigorovich et al. 2008). *Dreissena rostriformis bugensis* has displaced *D. polymorpha* from deeper waters of Lake Michigan and potentially elsewhere (Cuhel and Aguilar 2013). Comparatively fewer *D. rostriformis bugensis* records exist in natural history museum collections, and likely due to their phenotypic plasticity and superficial similarities with *D. polymorpha* (Beggel et al. 2015), their occurrences are often noted only as “Zebra Mussels” when encountered in the wild by biologists or citizen-scientists.

Distinguishing characteristics (Figure 3). Dreissenids are small (< 30 mm) bivalves that have a triangular or D-shaped white shell with brown to black zigzagged patterns. *Dreissena polymorpha* and *D. rostriformis bugensis* can be distinguished from each other by their shell morphology. *Dreissena polymorpha* tend to be flat on the hinged side while *D. rostriformis bugensis* are more rounded. However, because freshwater mollusks exhibit phenotypic plasticity, species differentiation among dreissenids can be difficult, and therefore genetic identification should be relied upon (Kerambrun et al. 2018).

BIVALVIA: SPHAERIIDAE—Mottled Fingernail Clam *Eupera cubensis* (Prime, 1865) (Figure 5)

Eupera cubensis is native to the southern United States, including the lower Mississippi River drainage at Bayou Pierre and Ramblin’ Bayou, Louisiana (Walker 1915; Heard 1965). In 2006, *E. cubensis* was collected in Illinois throughout the Chicago Sanitary and Ship Canal (CSSC), a 50-km long artificial waterway within the CAWS (Sneen et al. 2009). Because the CSSC is a navigation channel with a substantial amount of commercial traffic, Sneen et al. (2009) speculated that *E. cubensis* was attached to a shipping vessel, likely via byssal attachment. Byssal threads are somewhat unusual in Sphaeriidae but are known to occur in *Eupera* species (Heard 1965). *Eupera cubensis* has been reported from four sites in Illinois and appears to be contained within a 35 km stretch in the lower two-thirds of the CSSC in Cook and Will counties, Illinois (Figure 6). The species has not been collected since 2010 despite targeted surveys (D. Gallagher, Metropolitan Water Reclamation District of Greater Chicago, pers. comm., 2020). Benthic sampling in the CSSC is difficult and not routinely conducted, and we believe *E. cubensis* could be more widespread than current data suggest. It is unknown what effects *E. cubensis* will have on aquatic assemblages (Sneen et al. 2009). Jacobs and Keller (2017) scored *E. cubensis* as a low threat to aquatic ecosystems—one that has little to no discernible effects on existing biota.

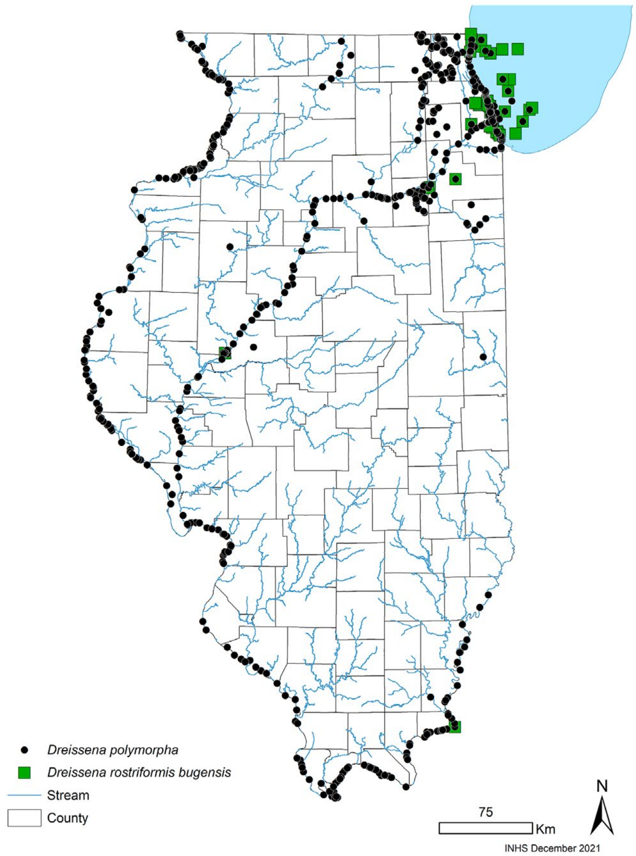

FIGURE 4 Distributions of Zebra Mussel *Dreissena polymorpha* and Quagga Mussel *Dreissena rostriformis bugensis* in Illinois.

Distinguishing characteristics (Figure 5). *Eupera cubensis* is a small (< 10 mm), round, thin-shelled bivalve. Dark mottling radiating from umbo (Sneen et al. 2009) distinguishes this species from other fingernail clams (Sphaeriidae), and the lack of elevated concentric ridges distinguishes this species from *Corbicula*.

BIVALVIA: SPHAERIIDAE—European Fingernail Clam *Sphaerium corneum* (Linnaeus, 1758) (Figure 5)

As its name implies, the European Fingernail Clam is native to Eurasia, including Europe (Mills et al. 1993). *Sphaerium corneum* has been reported in the eastern Laurentian Great Lakes basin (i.e., Lake Erie, Lake Ontario, and the St. Lawrence River) as early as the 1920s (Grigorovich et al. 2003) but has yet to be reported in Lake Michigan. However, we discovered one lot from the Field Museum (FMNH 108062) that was collected in 1958 in Lake Michigan, Cook County. The means of introduction into the United States is unknown (Mills et al. 1993) but likely attributable to ballast waters (Grigorovich et al. 2003). No other records for the species in Lake Michigan have been found (Figure 6). Given the difficulty in identifying fingernail clams, and the lack of benthic sampling that occurs in Lake Michigan, we believe *S. corneum* could be more widespread than current data suggest. As with *E. cubensis*, it is unknown what effects, if any, *S. corneum* will have on aquatic assemblages.

Distinguishing characteristics (Figure 5). *Sphaerium corneum* is a small (< 15 mm), oval, thin-shelled bivalve that has a brown to gray and somewhat inflated shell. The shell has evenly spaced striae that become finer and fade out toward the umbo. The second and fourth cardinal teeth are narrow and very close to parallel, and the latter overlaps the former, whereas the third cardinal is parallel to the hinge plate and expanded and often bifurcates posteriorly (Mackie et al. 1980). Like other fingernail clams, *S. corneum* can be difficult for nonspecialists to conclusively identify due to its small size, and this species could be misidentified or underrepresented in datasets.

GASTROPODA: BITHYNIIDAE—Faucet Snail (= Mud Bithynia) *Bithynia tentaculata* (Linnaeus, 1758) (Figure 7)

Bithynia tentaculata, native to Europe, was potentially introduced into North America in the 1870s via ship-ballast water (Berry 1943; Mills et al. 1993). However, it was reported from Pleistocene deposits in northeastern Illinois and, therefore, might have been present in North America before European colonization (Baker 1928; Cummings 1991). Mills et al. (1993) stated that modern-day populations in the Laurentian Great Lakes are descendants of the nineteenth-century introduction and, therefore, we do not consider *B. tentaculata* native to Illinois.

Bithynia tentaculata was reported as the most abundant nonindigenous aquatic mollusk species in the Laurentian Great Lakes prior to the arrival of *Dreissena* (Baker 1902; Berry 1943; Mills et al. 1993) and has become one of the most widespread nonindigenous aquatic gastropods worldwide (Preston et al. 2022). Baker (1902) stated, "The Lake View water supply [of Chicago] has been seriously threatened by the presence of this snail. The small service pipes became choked and in many private houses a tumblerful of these animals was taken from the faucet. Investigation at the Lake View crib showed that the screens were provided with such a large mesh that the eggs gained access to the main tunnel and there developed, the force of the water drawing them farther and farther into the tunnel until they finally appeared in the service pipes." It can cause displacement of pleurocerid snails as a result of these hyperdensities (Harman 2000).

Despite the dire account of Baker (1902), the distribution of *B. tentaculata* has not drastically expanded its range and become hyperabundant like other nonindigenous aquatic mollusk species have (e.g., *Corbicula* and *Dreissena*). Within Illinois, *B. tentaculata* has been reported from four counties since 1871 (Figure 8). However, it has been collected from the CAWS and, therefore, can expand elsewhere through the navigable water system. Jacobs and Keller (2017) scored *B. tentaculata* as a high threat to aquatic ecosystems—one that can cause discernible decline in the abundance of existing biota and can become a dominant component of the food web. Lastly, *B. tentaculata* is a host for several non-native trematode taxa that cause mortality in tens of thousands of waterbirds every year in North America (Bachtel et al. 2019; Preston et al. 2022).

FIGURE 5 Mottled Fingernail Clam *Eupera cubensis* (top left), European Fingernail Clam *Sphaerium corneum* (top right), New Zealand Mudsnail *Potamopyrgus antipodarum* (middle left), Big-eared Radix *Radix auricularia* (middle right), and European Stream Valvata *Valvata piscinalis* (bottom).

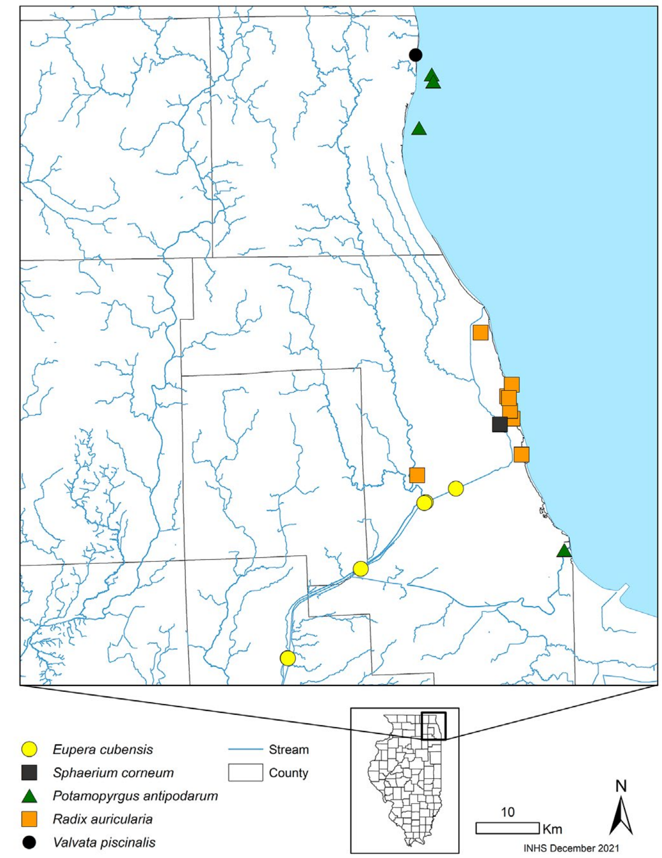

FIGURE 6 Distributions of Mottled Fingernail Clam *Eupera cubensis*, European Fingernail Clam *Sphaerium corneum*, New Zealand Mudsnail *Potamopyrgus antipodarum*, Big-eared Radix *Radix auricularia*, and European Stream Valvata *Valvata piscinalis* in Illinois. *Eupera* image modified from that published in Sneen et al. (2009).

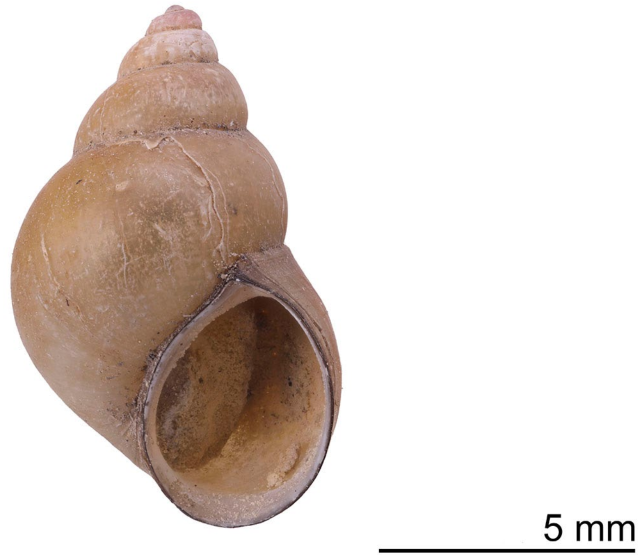

FIGURE 7 Faucet Snail (= Mud Bithynia) *Bithynia tentaculata*.

Distinguishing characteristics (Figure 7). *Bithynia tentaculata* has a small (< 12 mm), coiled shell with four to five coils (whorls). The animal is dextral (= shell opening on right when the animal is pointed up), is light brown to black in color, and has a chalky operculum (= "trap door" that covers the opening) with concentric rings that resemble a bullseye when the animal is alive (the operculum is often missing when the snail is dead and the shell is empty). *Bithynia tentaculata* can be difficult for nonspecialists to conclusively identify due to its small size and need for magnification, and this species could be misidentified or underrepresented in datasets.

GASTROPODA: TATEIDAE — New Zealand Mudsnail *Potamopyrgus antipodarum* (Gray, 1853) (Figure 5)

The New Zealand Mudsnail, as its name implies, is native to New Zealand. It was first documented in the United States in Idaho's Snake River in 1987 and has since spread throughout many western states in addition to the Laurentian Great Lakes (Zaranko et al. 1997; Kerans et al. 2005). Within the Great Lakes, *P. antipodarum* was first discovered in Lake Ontario, New York, in 1991 (Zaranko et al. 1997) but has since spread into the other lakes (Levri et al. 2007; Levri et al. 2012). The first collection of *P. antipodarum* in Illinois was from Lake Michigan in 2006 (USGS 252814), approximately 3 km off shore from Waukegan in Lake County. A second population was discovered in 2016 at Calumet Harbor in Cook County (USGS 1421451). No other records for *P. antipodarum* in Illinois exist to our knowledge (Figure 6). However, *P. antipodarum* could be more widespread within the Lake Michigan basin because of undersampling or misidentification, as these minute snails (< 5 mm) are one of the most widespread global nonindigenous aquatic gastropods (Preston et al. 2022). Additionally, *P. antipodarum* is often encountered in relatively deep water (> 4 m) in the Great Lakes (Zaranko et al. 1997; Levri et al. 2007), which are areas not frequently sampled.

Zaranko et al. (1997) speculated multiple introductions of *P. antipodarum* into North America and stated that the introduction into Lake Ontario likely occurred via ballast water from transoceanic vessels. Once *P. antipodarum* becomes established, the snail disperses via human-mediated activities, such as contaminated ballast waters, live wells or holding tanks, or recreational equipment (e.g., wading gear), or via zoochory or fluvial currents (Zaranko et al. 1997; Kerans et al. 2005). Alexandre da Silva et al. (2019) predicted areas at risk of invasion by *P. antipodarum* and suggested that much of North America, including the Great Lakes, is unsuitable based upon bioclimatic and hydroclimatic models. However, the authors did suggest climate change could negate their predictions and allow the expansion of *P. antipodarum*.

The ecological effects of *P. antipodarum* in the Laurentian Great Lakes are not well studied (Levri et al. 2007). However, the dispersal of the snail into inland streams could cause significant, complex ecological effects on the structuring of aquatic communities (Kerans et al. 2005). All introduced populations of

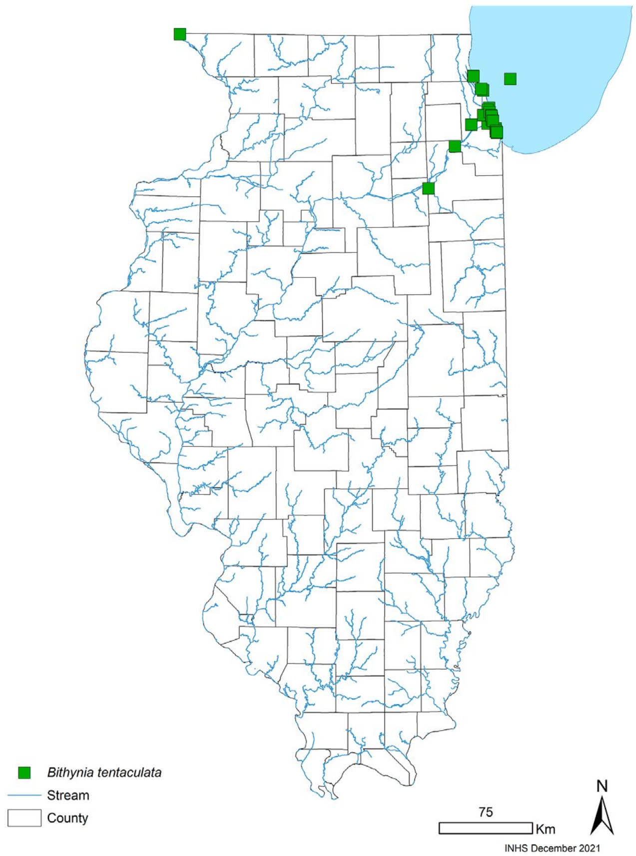

FIGURE 8 Distribution of Faucet Snail (= Mud Bithynia) *Bithynia tentaculata* in Illinois.

P. antipodarum in North America are gynogenetic, consisting of genetically identical females that clone themselves and birth live young. *Potamopyrgus antipodarum* can reach densities of 800,000 / m² (Dorgelo 1987), which can modify the interactions between primary producers and higher consumers by altering nitrogen and carbon cycles (Hall et al. 2003), and can compete with native grazers (e.g., other snail species and caddisflies) for food and space (Kerans et al. 2005; Riley et al. 2008). *Potamopyrgus antipodarum* effects can also proliferate through food webs and can negatively influence higher trophic levels because it is a poor food choice for secondary consumers like fishes, thus causing declines or reductions in fitness for these predators (Hall et al. 2006; Vinson and Baker 2008; Bruce and Moffitt 2010).

Distinguishing characteristics (Figure 5). *Potamopyrgus antipodarum* has a minute (< 5 mm), coiled-spiral shell that is dextral. It has an operculum that is often missing when the snail is dead and the shell is empty. Like other minute gastropods, *P. antipodarum* can be difficult for nonspecialists to conclusively identify due to its small size and need for magnification, and this species could be misidentified or underrepresented in datasets

GASTROPODA: LYMNAEIDAE — Big-eared Radix *Radix auricularia* (Linnaeus, 1758) (Figure 5)

Big-eared Radix, also called European Ear Snail (Jacobs and Keller 2017), is native to Europe and Asia (Jokinen 1992). It was first recorded in North America from the Hudson River, Albany County, New York, before 1869 (Strayer 1987). Around 1900 the species was collected in a greenhouse and surrounding lily pond from Chicago's Lincoln Park, Cook County, Illinois (Baker 1901). No other *R. auricularia* findings have been recorded outside Cook County in Illinois since the 1920s (Figure 6). We and others (Cummings 1991; Jacobs and Keller 2017) believe this species no longer exists in Illinois.

Radix auricularia was found in the Lake Erie basin in 1911 and in the Lake Ontario basin in 1930 (Mills et al. 1993). Mills et al. (1993) suggested that the sporadic distribution pattern of *R. auricularia* likely occurred from multiple, widespread introductions into North America. *Radix auricularia* has dispersed through human-mediated mechanisms, including aquarium releases and accidental and/or unintentional releases (Mills et al. 1993). Baker (1901) speculated that the snail had been introduced into Lincoln Park through imported greenhouse plants. Similarly, Goodrich (1911) suggested contaminated greenhouse plants for the introduction into the Lake Erie basin. It is unknown what, if any, effects *R. auricularia* had on the native aquatic gastropod fauna or what factors might have contributed to the snail's failed establishment.

Distinguishing characteristics (Figure 5). *Radix auricularia* has a thin, roundly ovate but very inflated shell that does not exceed 25 mm in height. The last whorl is broadly open and comprises 90% of the shell volume, and the spire is short, conic, and steeply pointed. Being a lymnaeid, *R. auricularia* lacks an operculum and is dextral.

GASTROPODA: VALVATIDAE—European Stream Valvata *Valvata piscinalis* (Müller, 1774) (Figure 5)

Valvata piscinalis is native to Europe, Caucasus, western Siberia, and Central Asia (Grigorovich et al. 2005). It was first recorded in North America in 1897 in Lake Ontario near the mouth of the Genesee River, Monroe County, New York. Since then, it has been collected throughout the Laurentian Great Lakes, including the southern portion of Lake Michigan (Grigorovich et al. 2005). Grigorovich et al. (2005) found a single individual on soft-bottomed substrates at nearly 9 m deep near the [Bull] Creek–Lake Michigan confluence in 2002. This record was labeled as "Butt Creek" (Grigorovich et al. 2005) but was in fact collected at the mouth of Bull Creek near Farnum Point at Illinois Beach State Park in Lake County, Illinois (Jan Ciborowski, University of Calgary, pers. comm., 2021). We could not locate a voucher specimen of this account and, therefore, report it simply as a published record (Figure 6). There is no evidence that *V. piscinalis* is reproducing in Illinois, and we consider its status unknown. Given that the species has been collected in deeper waters and occurs in low densities in Lake Michigan, it is possible *V. piscinalis* occurs in the Illinois portion of Lake Michigan but has gone unnoticed due to sampling and identification biases against small species.

FIGURE 9 Chinese Mysterysnail *Cipangopaludina chinensis* (left) and Japanese Mysterysnail *Heterogen japonica* (right).

Valvata piscinalis disperses through human-mediated mechanisms, including ballast waters, and can populate a wide variety of habitats, including canals, large rivers, and lakes (Mills et al. 1993; Grigorovich et al. 2005). The species is considered invasive because it is hermaphroditic, has rapid growth, early maturation, and high fecundity, and can tolerate adverse environmental conditions (Grigorovich et al. 2005). In some areas of invasion (e.g., Oneida Lake, New York), *V. piscinalis* has reached densities > 200 individuals / m^2 (Grigorovich et al. 2005). *Valvata piscinalis* occurs on a variety of substrates, including on aquatic vegetation where it deposits egg masses during spawning, and in mud and silted sand where it hibernates during the winter (Grigorovich et al. 2005, and references therein). *Valvata piscinalis* can negatively affect native aquatic gastropod assemblages through direct competition of food and habitat (Grigorovich et al. 2005).

Distinguishing characteristics (Figure 5). *Valvata piscinalis* has a minute (< 5 mm), dextrally coiled shell with a blunt but slightly raised spire and 4–5 rounded whorls. Valvatids lack an operculum and can be distinguished from similarly shaped planorbid species by being less planar. Like other minute gastropods, *V. piscinalis* can be difficult for nonspecialists to conclusively identify due to its small size and need for magnification, and this species could be misidentified or underrepresented in datasets.

GASTROPODA: VIVIPARIDAE — Chinese Mysterysnail *Cipangopaludina chinensis* (Gray in Griffith and Pidgeon, 1833), and Japanese Mysterysnail, *Heterogen japonica* (von Martens, 1861) (Figure 9)

Mysterysnails (e.g., *Cipangopaludina* spp. and *Heterogen* spp.) are large (up to 80 mm) viviparid gastropods native to Asia that have become established throughout North America (Jokinen 1982; Saito et al. 2020). The two species, which were at one time placed in the same genus, are morphologically difficult to distinguish from one another (Smith 2000; Hirano et al. 2019; Saito et al. 2020).

Cipangopaludina chinensis was first reported in the United States in the early 1890s at food markets in San Francisco (Wood 1892) and has since been collected throughout the United States and Canada (Streans 1901; Johnson 1915; Jokinen 1982; Burch 1989; Smith 2000; Solomon et al. 2010). It was first documented in Illinois at the outer lagoon at Jackson Park, Chicago, in 1938 (Haas 1939). Since then, *C. chinensis* has been collected in 23 counties, including in kettle lakes, borrow pits, farm ponds, and streams throughout northern Illinois, as well as several locations downstate (Figure 10). The related *Heterogen japonica* is also extant in Illinois but does not appear to be as prevalent as *C. chinensis*, as it has only been recorded from 9 counties in the state since 1995. Given their morphologic similarities, it is likely *H. japonica* is underreported in Illinois. Due to uncertainty in identification, we have combined records for *C. chinensis* and *H. japonica* in the map (Figure 10); together, they have been collected in 27 counties. Given their expansive, disjunct distributions in Illinois, humans (e.g., water gardeners, aquarists, anglers, and boaters) are suspected to be responsible for the spread of *C. chinensis* and *H. japonica* (Mills et al. 1993; Bury et al. 2007; Solomon et al. 2010; Hirano et al. 2015).

Mysterysnails inhabit quiet water, either in slow-moving streams or pond and lake margins, where there are some vegetation and muddy substrates. Like other viviparids, mysterysnails give birth to live, fully developed young and, therefore, can achieve hyperdensities in areas they invade. Based on our own observations, mysterysnails are hardy (e.g., surviving out of water

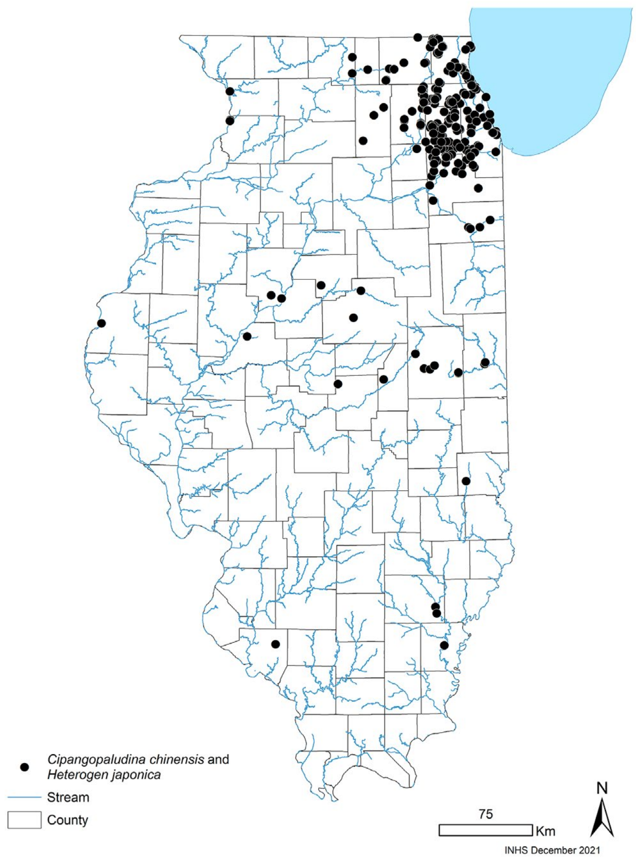

FIGURE 10 Distributions of Chinese Mysterysnail *Cipangopaludina chinensis* and Japanese Mysterysnail *Heterogen japonica* in Illinois.

~3 days at 15°C) and can reach densities of ~200 adults / m^2. Mysterysnails have become one of the most widespread nonindigenous aquatic gastropods worldwide (Preston et al. 2022). Due to its wide distribution and high densities, some authors have speculated that *C. chinensis* could negatively affect native gastropod assemblages (Bury et al. 2007; Johnson et al. 2009). In fact, Jacobs and Keller (2017) suggested *C. chinensis* is a great threat to aquatic ecosystems and can cause discernible decline in the abundance of existing biota and become a dominant component of the food web. In addition, *C. chinensis* has been known to carry and transmit parasites (e.g., the trematode *Aspidogaster conchicola* Baer, 1827) that affect humans and freshwater mussels (Huehner and Etges 1977; Chung and Jung 1999; Bury et al. 2007; Gangloff et al. 2008).

Distinguishing characteristics (Figure 9). *Cipangopaludina* spp. and *Heterogen* spp. grow up to 80 mm tall and are olive to chestnut colored. They are dextral, have an operculum that is often missing when snail is dead, and their shells are often malleated (i.e., have small indentations in the shell that resemble tiny hammer marks). Although they resemble some of Illinois' native species in the genera *Campeloma* and *Viviparus*, both *C. chinensis* and *H. japonica* are distinguished by their larger size, pointed spire (in some individuals), malleated surface, and lack of banding at any growth stage. Juveniles also often have hirsute lines arranged radially along the shell. When compared to one another, *H. japonica* tends to be higher spired than *C. chinensis*.

Species recorded but not included

Cummings (1991) listed four nonindigenous aquatic mollusk species occurring in Illinois: *Corbicula fluminea*, *Dreissena polymorpha*, *Radix auricularia*, and the Bloodfluke Planorb *Biomphalaria glabrata* (Say, 1818). However, no evidence of *B. glabrata* occurring in Illinois, other than by Cummings (1991), has been found, and we consider his reporting an error. Cummings (1991) mentioned *Bithynia tentaculata* but stated the species "has been reported from Pleistocene deposits in Chicago, and it may, therefore, have been present in North America" before European colonization; however, more recent publications (e.g., Mills et al. 1993) have suggested modern-day *B. tentaculata* populations in the Laurentian Great Lakes are nonindigenous. Since Cummings (1991), seven species have been recorded in Illinois: two *Corbicula* species (Form B and Form D), *Dreissena rostriformis bugensis*, *Eupera cubensis*, *Potamopyrgus antipodarum*, *Heterogen japonica*, and *Valvata piscinalis*. One species, *Cipangopaludina chinensis*, was present in Illinois by 1990 (e.g., Haas 1939) and accidentally omitted by Cummings (1991).

Several other species, including the Atlantic Rangia (= Common Rangia or Wedge Clam) *Rangia cuneata* (Sowerby, 1832), apple snails *Pomacea* spp., and various marine snails (e.g., Neritidae and Trochidae), have been collected in Illinois but have not, to our knowledge, established reproducing populations at any point in time (INHS Mollusk Collection data). Despite seven records of *R. cuneata* from Illinois, we believe this brackish-water bivalve was never established in the state. It was a popular shell traded among Native Americans, including those that inhabited or visited the Cahokia Mounds along the Mississippi River in St. Clair County (Baker 1923). We have sporadic records (< 2 records per species) of *Pomacea* spp. and Neritids but believe the physicochemical conditions of Illinois waterways do not match the preferred habitat characteristics of either group (e.g., *Pomacea* and Neritids are subtropical) (Burch 1989; Johnson et al. 2013). Therefore, we omitted them from consideration as being established in Illinois and consider them serendipitous collections of aquarium releases. Several other nonindigenous aquatic mollusk species (i.e., Chinese Pond Mussel *Sinanodonta woodiana* [Lea, 1834], and Greater European Pea Clam *Pisidium amnicum* [Müller, 1774]), occurring throughout North America have yet to be collected in Illinois (see Mills et al. 1993; Watters 1997; Bogan et al. 2011; Jacobs and Keller 2017; O'Leary et al. 2021). Some species may never reach Illinois, whereas others, especially when considering those taxa established elsewhere in the Laurentian Great Lakes basin, as well as the effects of climate change and global shipping routes, could eventually establish populations in Illinois.

Lastly, the Banded Mysterysnail *Viviparus georgianus* (Lea, 1834), has expanded its range in Minnesota and Wisconsin due to anthropogenic activities (e.g., Mills et al. 1993; Bury 2007;

Solomon et al. 2010). It is popular among aquarium enthusiasts, but we believe *V. georgianus* has always been native to Illinois. Clench and Fuller (1965) argued that North America might be the epicenter for Viviparidae, and the group has only recently (on a geological time scale) begun to recolonize glaciated areas. The INHS Mollusk Collection has *V. georgianus* records from northern Illinois that were collected before 1920 (e.g., R. E. Richardson collection in upper Illinois River drainage; INHS 42069), so it seems likely that the snail was established throughout Illinois prior to the popularity of the aquarium trade.

Conclusion

It is important to recognize the sometimes innocent, yet disastrous, ramifications nonindigenous species could have on our native waterways, especially given that climate change will create conditions favorable for many species not presently found in more-northern latitudes (i.e., *Corbicula*) (Cvetanovska et al. 2021). As conservation biologists, we must recognize these pathways and disseminate knowledge to the public to limit future releases. There are many simple, preventative measures people can take to slow the spread of nonindigenous species: never releasing unwanted aquarium animals or live fishing bait into the wild; inspecting boats and trailers for mud, plants, and undesired species; and draining, disinfecting, and drying equipment and gear when moving from one water body to another. Lastly, new data records are constantly being added, particularly in sources such as iNaturalist that use citizen-science sourced data. If encountered in the wild, citizen-scientists can take a photograph of the nonindigenous species, record its location, and report it through iNaturalist or share with natural resource agencies or natural history museums. Natural resource agencies and natural history museums are often hindered by limited monetary and time resources, and citizen-scientist data can help offset these limitations and contribute important data (Tiemann et al. 2014; Di Decco et al. 2021). These data help document new locations of nonindigenous aquatic mollusk species, such as *D. rostriformis bugensis* or *C. chinensis*, as citizen-scientists supported by interactive educational campaigns are an effective means of tracking nonindigenous species (Barbato et al. 2021; Di Decco et al. 2021; Kingsbury et al. 2021).

Nonindigenous aquatic mollusks can alter aquatic ecosystems—from modifying habitats to outcompeting native mussels. However, capturing these multifarious interactions often requires long-term data sets and judicious interpretation of the complex relationships that occur (Strayer et al. 2017). Rapid detection, identification, and adaptive management development are critical in diminishing the spread and ultimately minimizing the negative environmental and economic effects of nonindigenous aquatic mollusks. Having a better understanding of the interactions between native and nonindigenous aquatic mollusks will greatly benefit stakeholders. Works like ours, coupled with those about fishes (e.g., Laird and Page 1996; Irons et al. 2009), will help future researchers as they build models to predict the dispersion pathways of Illinois' nonindigenous aquatic mollusks. Lastly, we believe several taxa, especially those that are morphologically similar (e.g., *Corbicula* spp., *Dreissena* spp., and mysterysnails) or are minute and difficult to identify (e.g., *B. tentaculata* and *V. piscinalis*) could be underreported due to the lack of sampling programs and taxonomic expertise. It is critical for museums and scientists to maintain voucher specimens, as they document the authenticity of a record and are a tool for identifying localities of the taxon (Rocha et al. 2014).

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