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# A lakewide survey of Asian clam (*Corbicula fluminea*) distribution at warmwater discharges in Lake Michigan

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ABSTRACT

The Asian clam *Corbicula fluminea* is among the most prolific aquatic invaders in the world; but in colder mid-latitude areas, like the Laurentian Great Lakes, their population expansion has likely been limited by poor over-winter survival. In these areas, Asian clams are typically found in thermal refugia like warmwater discharges from industrial facilities. We sought to identify the current extent of Asian clam populations in Lake Michigan and waters immediately adjacent to it, specifically at locations most likely to harbor overwintering populations – industrial warmwater discharges. During April–May 2017, we surveyed 17 locations around Lake Michigan. Evidence of Asian clam populations was found at four sites, though live specimens ($n = 3$) were only found at the Indiana Harbor Ship Canal in East Chicago, IN. Shells or fragments of shells were found at Green Bay, WI, Waukegan, IL, and Port Sheldon, MI. Our findings indicate that although Asian clams are present in Lake Michigan, they are relatively rare, and remain isolated to a few small pockets of over-wintering habitat.

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## Introduction

Asian clams *Corbicula fluminea* are among the most widespread and invasive aquatic organisms in the world. This species, native to the large river drainages of Southeast Asia, was likely introduced to North America in the Pacific Northwest during the late 1800s, but was first documented in the 1920s (McMahon, 1982; Sousa et al., 2008). Despite its widespread abundance, considerable uncertainty exists surrounding the genetic identification of this taxon due to diverse life-histories, varying morphologies, and reproductive habits (i.e., androgenesis, hermaphroditism, sexual reproduction). Genetic studies have identified at least four distinct New-World morphotypes: forms A and B (Britton and Morton, 1986), C (Lee et al., 2005), and D (Tiemann et al., 2017), three of which (A, B, and D) are found in the Great Lakes region. The diversity of forms and reproductive habits may accelerate their ability to adapt to new environments, including those found in the Great Lakes. One of the advantages aiding the spread of this species, compared to native bivalves, is the development of a fully formed juvenile that is released from the brood sac. This allows for rapid dispersal and population growth without the need for an intermediate host (Sousa et al., 2008).

The habitat preferences of this bivalve are as diverse as their reproductive habits. They are tolerant of many substrates but tend to prefer sandy areas in lakes, rivers, and reservoirs (Strayer, 1999). Populations have become widely established from cold, northern lakes (Lake George, New York; Young and Wick, 2017) to warm, southern rivers and reservoirs (Texas; Karatayev et al., 2005). Under ideal conditions they can filter seston from the water at a rate of 109–1370 mL/h (Lauritsen, 1986) and achieve densities of 1000–3000 clams/m$^2$ or more (McMahon, 1982; Hornbach, 1992; Ilarri et al., 2014). In North America, Asian clams are most commonly found at warmer, lower latitudes (25°–41° N latitude) south of the Laurentian Great Lakes region, and their primary barrier to further northwards expansion is likely poor overwinter survival in cold waters for extended periods of time (Smith et al., 2018). Most authors assume a lower thermal tolerance of 2 °C for Asian clams based on work by Mattice and Dye (1976), but a more recent laboratory study found 0 °C to be a more appropriate thermal minimum (Müller and Baur, 2011). Overwinter mortality for this species is influenced by water temperature, duration of exposure, and the size of the individual (Müller and Baur, 2011). Larger clams (e.g., 30 mm) have a higher probability of survival when exposed to cold temperature than small clams (e.g., ≤ 5 mm) and survival rates decrease with duration of exposure.

Currently, Lake Michigan and the Upper Midwest (42°–47° N latitude) are at the northernmost extent of the Asian clams' range, most likely due to cold, harsh winters (water temperature 0–2 °C for weeks-months) that limit overwinter survival. These severe northern winters effectively prevent this species from becoming as widespread and abundant as they are further south, limiting their potentially negative ecological and economic consequences. Warmwater discharges from industrial facilities are some of the few thermal refuges where this species can successfully overwinter at northern latitudes (Clarke, 1981; French and Schloesser, 1991; Simard et al., 2012). Unfortunately,

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as the earth continues to warm due to anthropogenic climate change, this highly adaptable species will become less thermally limited, allowing it to shift its range further north and become more abundant within the Lake Michigan drainage basin. During this century alone, mean air temperature over the Great Lakes basin is expected to warm by 3°–5 °C (Hayhoe et al., 2010; Wang et al., 2016) and those changes will translate into warmer water temperatures across the Great Lakes.

Given the likely expansion of this invasive species, it is important to understand the current extent of their distribution within Lake Michigan which is already a heavily disturbed ecosystem (Cuhel and Aguilar, 2013). Asian clams are documented in the Illinois River, a system artificially connected to the Great Lakes via the Chicago Area Waterway System (Tiemann et al., 2017) and several other waterways connected to Lake Michigan (Foster et al., 2017). After extensive literature review and contacts with regional aquatic invasive species coordinators and researchers, we identified a few currently known populations in the Lake Michigan basin; but to our knowledge, there has never been a comprehensive effort to define the extent of the Asian clam population within the nearshore zone of Lake Michigan and directly adjacent waters. Because the locations where these species are likely to overwinter are easily identified, we wanted to perform a thorough survey of these areas that addressed two objectives: 1) identify whether warmwater discharges in Lake Michigan support extant populations of Asian clams and 2) identify patterns in presence or absence of Asian clams across sites relative to habitat type, proximity to potential source populations, competition, food availability, or introduction vectors. Providing a lakewide survey of the type described above would be of interest to regional resource managers and should provide insight into the areas from which this species is likely to disperse as lake temperatures warm.

## Methods

### Study area

Lake Michigan is the third largest of the Laurentian Great Lakes by surface area (58,030 km$^2$) and has >2300 km of shoreline. The south shore of the lake is more heavily populated and industrialized than the north shore – therefore, our sampling was concentrated in the southern half of the lake. We used local knowledge, satellite imagery, and on-the-ground observation to identify potential warmwater discharges directly on Lake Michigan or waters immediately connected to the lake (i.e., harbors, rivers, drowned river mouth lakes). Sites identified as potential warmwater discharges included: nuclear, coal-fired, and natural gas power plants; steel making facilities; and wastewater treatment plants. Each potential location was scrutinized to identify whether the facility remained operational; and if so, whether they had permits for discharging warmwater. We identified 17 facilities on Lake Michigan or adjacent waters that were operational (at least intermittently) and potentially discharging warmwater (Table 1; Fig. 1).

### Experimental design

For each site we established a 5 × 5 square sampling grid (25 cells) in ArcGIS™ at the discharge of each facility that was either 50 m or 75 m on a side, depending on the space available for sampling at each site. Sites confined by sea walls or canal width (n = 7) required the 50-m sample grid, but at most sites the 75-m (n = 10) grids were used. Sample grids were centered on the discharge. In each box of the grid, we established a sample point at the centroid with an assigned number (1–25). Ten sample points were randomly chosen to be sampled from each grid, and sample points were randomized for each site. In the field, if flow from the discharge was too strong, or if it was too shallow to sample effectively, then the next randomly assigned sample point was used.

### Field sampling

All sampling was performed during April and early May 2017 when water temperatures in the main lake were still cool (<15C), allowing us to observe thermal differences between the industrial discharge and receiving waters. At each sample point, benthic sediment samples were collected using a petite Ponar sampler (volume = 2.4 L; area = 0.024 m$^2$). Composition of the dominant sediments was assessed visually in the field and categorized by cobble, gravel, sand, silt, clay, muck, detritus, and shells (Dreissenidae) based on methods described by Simonson et al. (1993). Samples were washed through a 500 μm sieve bucket, and all collected contents were placed in a labeled bottle and fixed with 95% ethanol (ETOH). In the laboratory, samples were sorted and all live Asian clams were identified, enumerated, weighed (wet weight; g), and measured for total length from anterior to posterior of the shell (TL; mm) with a digital caliper. Dead specimens (i.e., relic shells) were measured for TL and enumerated. All live specimens and relic shells were inspected for evidence of umbo holes that can form in low pH waters causing mortality (Kat, 1982). Evidence of biofouling by zebra (*Dreissena polymorpha*) and quagga mussels (*D. bugensis*) was recorded because *Dreissena* species are potential competitors with Asian clams for resources and space in the Great Lakes; interactions between these species are poorly understood in the field. Biofouling was considered to be occurring if live zebra or quagga mussels were attached to live Asian clams.

For each Ponar sample we recorded depth (m) and measured water quality parameters using an EXO2 multiparameter sonde (YSI, Inc).

**Table 1**
Asian clam (*Corbicula fluminea*) survey locations at warmwater discharge facilities around Lake Michigan. All facilities intermittently or continuously discharged water warmer than their receiving environment during winter, the critical period for survival of Asian clams in mid-latitude areas.

| Location (water body) | ID | Facility (ownership; fuel generation [if applicable]) | Latitude | Longitude |
|---|---|---|---|---|
| Green Bay, WI (Fox River mouth) | 1 | Pulliam Power Plant (Wisconsin Public Service; coal fired) | 44.539225 | −88.006429 |
| Two Rivers, WI (Lake Michigan) | 2 | Point Beach Nuclear Plant (Next Era Energy Resources; Nuclear) | 44.281295 | −87.533925 |
| Manitowoc, WI (Lake Michigan) | 3 | Manitowoc Power Plant (Manitowoc Public Utilities; coal fired) | 44.081281 | −87.654190 |
| Sheboygan, WI (Lake Michigan) | 4 | Edgewater Power Plant (Wisconsin Public Service; coal fired) | 43.716325 | −87.705188 |
| Milwaukee, WI (Menomonee River) | 5 | Valley Power Plant (We Energies; natural gas fired) | 43.032013 | −87.924773 |
| Oak Creek, WI (Lake Michigan) | 6 | Oak Creek Power Plant (We Energies; coal and natural gas fired) | 42.853348 | −87.830792 |
| Waukegan, IL (Lake Michigan) | 7 | NRG Waukegan generating station (NRG Energy; coal fired) | 42.393230 | −87.805525 |
| Winnetka, IL (Lake Michigan) | 8 | Village of Winnetka Power Plant (Illinois Municipal Electric Agency; natural gas) | 42.116341 | −87.729490 |
| Whiting, IN (Lake Michigan) | 9 | BP Lakefront Waste Water Purification Plant (BP P.L.C.) | 41.676364 | −87.475751 |
| East Chicago, IN (Indiana Harbor Ship Canal) | 10 | ArcelorMittal Indiana Harbor (ArcelorMittal; steelmaking facility) | 41.672748 | −87.442186 |
| Burns Harbor, IN (Port of Indiana - Burns Harbor) | 11 | ArcelorMittal Burns Harbor (ArcelorMittal; steelmaking facility) | 41.635796 | −87.147935 |
| Michigan City, IN (Lake Michigan) | 12 | Michigan City Generating Station (Northern Indiana Public Service Company; coal fired) | 41.723280 | −86.912247 |
| Covert, MI (Lake Michigan) | 13 | Palisades Nuclear Generating Station (Entergy; Nuclear) | 42.323421 | −86.315985 |
| Holland, MI (Lake Macatawa) | 14 | James De Young Power Plant (Michigan Public Power Agency; natural gas) | 42.795820 | −86.114848 |
| Port Sheldon, MI (Pigeon Lake) | 15 | J.H. Campbell Generating Complex (Consumers Energy; coal fired) | 42.904132 | −86.204381 |
| Grand Haven, MI (Grand River) | 16 | J.B. Sims Generating Station (Grand Haven Board of Light & Power; coal) | 43.067970 | −86.235001 |
| Filer City, MI (Manistee Lake) | 17 | T.E.S. Filer City Station LP (CMS Enterprises; biomass wood and coal fired) | 44.215125 | −86.283172 |

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