

The Introduction and Spread of the Zebra Mussel in North America

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Abstract

The zebra mussel, *Dreissena polymorpha*, is believed to have arrived in North America as a freshwater ballast stowaway in commercial vessels from Europe sometime around 1986. The mussel was first discovered in the Great Lakes in Lake St. Clair in June 1988. As a result of natural and human-influenced dispersal vectors, the intervening years have witnessed the intra- and interbasin transport of the zebra mussel throughout much of North America.

The mussel's first passage beyond the Great Lakes Basin was in 1991 when the mussel crossed New York State through the Erie Canal and Mohawk River into the Hudson River. By the end of 1993, zebra mussel-infested U. S. waters included: all of the U.S. shores of Lakes St. Clair, Erie, and Ontario; most of the Lake Michigan and Huron shores; Duluth-Superior Harbor in western Lake Superior; all or parts of the Arkansas, Calumet, Chicago, Cumberland, Des Plaines, Detroit, Genesee, Hudson, Illinois, Mississippi, Mohawk, Niagara, Ohio, Oswego, St. Lawrence, Susquehanna, and Tennessee Rivers; the Erie Canal; the St. Lawrence Seaway; three of the Finger Lakes; Saginaw Bay; and, Lake Champlain.

The expansion of the range of the zebra mussel in Canada, although initially rapid, has not been as dramatic as that in the United States. Since being discovered in Lake St. Clair in 1988, the mussels have spread throughout Lakes St. Clair, Erie, and Ontario; eastern Lake Huron; the St. Lawrence River; the Welland Canal; Georgian Bay; the Kawartha Lakes (interconnected to the Great Lakes); the Muskoka Lakes (overland transport); the Rideau Canal system; and, portions of the Ottawa River. To date, all of the Canadian zebra mussel sightings have been within the Great Lakes-St. Lawrence drainage basin.

Based upon atmospheric and surface water temperature data, it has been suggested that the mussels may ultimately infest most environmentally hospitable fresh surface waters of North America, south of central Canada, north of the Florida Panhandle, and from the Atlantic to the Pacific.

The Ballast Water Stowaway

The zebra mussel, *Dreissena polymorpha*, is native to the drainage basins of the Black, Caspian and Aral Seas in Eastern Europe and Western Asia. As commerce increased between Eastern, Central, and Western Europe, the mussel moved west, resulting in its introduction into several Central and Western European freshwater systems during the late 1700s (1790 - *River Danube, Hungary*; 1824- *London, England*; 1826- *Rotterdam, The Netherlands*; 1830- *Hamburg, Germany*; 1840- *Copenhagen, Denmark*; 1835- *River Rhine, Germany*; 1844-1867- *various river systems, France*). By the late- 1800s, the zebra mussel was found throughout Central and Western European inland waterways. By the 1940s, the mussel made its way into water of Scandinavia, and is currently undergoing a rapid range expansion throughout the waters of the former Soviet Union.

The actual pathway of the mussel's introduction into North America is unknown, but experts believe that it arrived here as a stowaway in cargo vessels originating from European freshwater ports. Although zebra mussels are capable of attaching to ships' hulls, their transoceanic transport in this manner is unlikely since the mussels cannot survive the salinity of open ocean saltwater for the time required for such a crossing. More likely, the mussels arrived in North America as an internal stowaway. Cargo ships carry significant amounts of ballast water to stabilize the vessels during transoceanic crossings; the less cargo on board, the more ballast water is carried in ballast tanks. When ballast tanks are filled, many forms of aquatic life in the source water are drawn into the tanks (one study found some 240 different plant and animal life forms which may be carried in ballast water tanks). Once in ballast tanks, these organisms can be transported to other areas and subsequently be discharged into the waters of foreign ports. If the receiving waters are of the appropriate type (salt for saltwater ballast, fresh for freshwater ballast) and quality, there is a possibility that some of the ballast "exotics" may survive and establish new, breeding populations. This is believed to have been how the zebra mussel reached North America. It is also believed that more than 30 other exotic aquatic organisms, such as the ruffe and the spiny water flea, likely were introduced into the Great Lakes via ballast water dumping, as well. The problem is not limited to the Great Lakes, however, but is of great concern worldwide in both fresh- and saltwater ports.

Why, if the zebra mussel was in Europe for hundreds of years, did it take so long to reach North America? While this is the first time that the mussel is known to have colonized North American waters, it is possible that small populations may have been dropped off in the past, but in numbers too small to become established as breeding colonies, or in areas where they could not survive changing environmental factors. Serendipity may have brought a number of factors together, resulting in the current situation. Although zebra mussels have been distributed throughout most of Eastern, Central and Western Europe for hundreds of years, populations were substantially reduced due to the pollution of European waterways as a result of the industrial revolution and runoff from World War I. Post-World War II efforts to cleanup those waters inadvertently resulted in a

reemergence of the zebra mussel in the years after the mid- 1950s.

On the receiving end of the equation, prior to the 1900s, most shipping to North America carried solid ballast (instead of water) which is less likely to be a major vector of aquatic organisms. There was also less shipping than today. Although water had become the predominant ballast material by the early-1900s, transoceanic crossings still took two or more weeks, during which time ballast water could become a very inhospitable place for aquatic organisms to live, reducing the possibility of live aquatic organisms being discharged into North American waters. With the advent of new, faster ships after World War II, more exotics could conceivably survive the crossing.

Following North America's own industrial revolution, the quality of many of our waters was degraded to the extent that survival of new aquatic organisms became questionable in many harbors. These waters have been substantially cleaned up since the mid-60s, making them a much more viable habitat for new aquatic introductions.

Three pieces of the puzzle were now in place: cleaner European waters to provide ballast water immigrants, faster ships carrying freshwater ballast to serve as the transmittal vectors, and cleaner North American waters to receive the immigrants. The final piece of the puzzle was supplied by the completion of the St. Lawrence Seaway in the late- 1950s, which provided the pathway for European-origin vessels (possibly carrying a number of exotics) to enter the Great Lakes. It is also possible that the increase in Eastern European shipping during the Soviet grain sales years of the late-70s and early-80s may have contributed to the number of gallons of European freshwater being purged from ballast tanks into the Great Lakes as those vessels took on cargo.

Mechanisms of Zebra Mussel Dispersal in North American Waters

Natural dispersal mechanisms for zebra mussels include swimming (during the first weeks of its life, a zebra mussel veliger is an actively swimming organism), water currents (both flowing streams and rivers and wind-driven waves), and attachment to other organisms (such as crayfish). Also suspected as a potential vector, but never quantified, is the attachment of mussels to feathers, feet, and legs of waterfowl and shorebirds, as well as transport on the fur of aquatic mammals.

Biologists believe, however, that interbasin transport of the zebra mussel throughout North America from infested waters of the Great Lakes and contiguous river systems into uninfested inland fresh surface waters will be very strongly enhanced by human influenced dispersal vectors. It is believed that the mussels will ultimately infest most susceptible (environmentally hospitable) waters of North America south of central Canada and north of the Florida Panhandle, and from Maine west to the California coast, a prediction which seems to be borne out by the rapidity with which the mussel has moved from the Great Lakes into inland river systems such as the Illinois, Susquehanna, Mississippi, Ohio, Tennessee, Arkansas, Ohio, and Hudson Rivers.

Major human-influenced dispersal vectors are interlake and interbasin transport of veligers in ship and barge ballast (the presence of zebra mussels in Duluth-Superior

Harbor in western Lake Superior is believed to be evidence of such commercial shipping transport) and juvenile and adult mussel attachment to ship, barge and recreational boat hulls. Other human influenced dispersal vectors include transport of juveniles and adults on or in recreational boats sailed or trailered from infested to uninfested waterbodies (zebra mussels can withstand desiccation for several days, depending upon relative humidity and temperature, thus allowing some transport while out of the water; mussels have been found on aquatic vegetation snagged on the props and trailers of boats being moved over land between water bodies); transport of veligers by commercial bait transport and fish stocking operations; in anglers' bait bucket water, and in recreational boat engine cooling water; in water flowing through navigation and irrigation canals (the Erie Canal provided an expressway across New York State from Lake Erie to the Hudson River); on or in equipment such as work barges, dredges, etc.; and by aquaria releases (this has been confirmed at a reservoir in the Province of Ontario).

The Zebra Mussel's Range Expansion in North America

The zebra mussel was first discovered in the Great Lakes Basin in routine samples taken from the bottom of Lake St. Clair in June 1988 (no one at that time was looking specifically for zebra mussels). Judging from the shell size of those mussels, it was theorized that the mussels had been introduced into the lake sometime in 1986. The first confirmed sighting in the western basin of Lake Erie was at South Bass Island (*Put-in-Bay, OH*) in October 1988.

1989

By early-summer 1989, extensive colonies of 30,000 to 40,000 individuals per square meter were reported on shoals in the shallow, nutrient rich, western basin of Lake Erie by the Ontario Ministry of Natural Resources. By the end of 1989, specimens were found in electric generating, public water treatment and industrial facility water systems in the Detroit River below Lake St. Clair, and on beaches and in power, water treatment and industrial facilities along most of the north and south shores of Lake Erie. By the end of that year, zebra mussels could be found throughout the entire Lake Erie shoreline (*Monroe, MI; Ashtabula, Cleveland, Sandusky, and Toledo, OH; Port Stanley and Nanticoke, ONT; Erie, PA; Dunkirk and Buffalo, NY*).

Adult mussels were first reported in Lake Ontario in Port Weller, ONT, at the mouth of the Welland Canal in November 1989 and on a navigation buoy approximately four miles off the Niagara Bar in December 1989. Adult mussels were also found attached to a barge and an icebreaker at a shipyard in Sturgeon Bay, WI. No mussels were found anywhere else in the vicinity; those found on the vessels were believed to have been transported there by the vessels (both had spent time in Lake Erie).

1990

1990 witnessed the mussel's rapid range expansion throughout the entire Great

Lakes basin, the Niagara River and the Welland Shipping Canal; the western and southern shores of Lake Ontario (*Rochester and Oswego, NY; St. Catherines, Hamilton and Toronto, ONT*); the Erie Canal from Buffalo, NY, on Lake Erie east to a point about one third of the way across the state; the northeastern end of Lake Ontario, the upper St. Lawrence River, portions of the St. Lawrence Seaway (*Picton, Kingston, and Cornwall, ONT; Snell and Eisenhower Locks*), the lower St. Lawrence River (*Ile D'Orleans, QUE*); virtually all of Lake St. Clair; southern and eastern Lake Huron (*Port Huron, MI; Godenrich and Port Elgin, ONT*); Saginaw Bay and Thunder Bay (*Alpena, MI*) on western Lake Huron; the southeastern and southern shores of Lake Michigan (*Grand Haven, Holland, and Muskegon, MI; East Chicago and Gary, IN*); western Lake Michigan (*Kenosha and Sheboygan, WI*), and the western end of Lake Superior in Duluth-Superior Harbor (*Duluth, MN; Superior, WI*).

1991

By February 1992, the zebra mussel had followed the Erie Canal to its confluence with the Mohawk River and all of the Mohawk River east to its confluence with the Hudson River (*Herkimer, Amsterdam, and Albany, NY*), marking the mussel's first passage beyond the Great Lakes Basin. The mussel then followed the Hudson River south (*Catskill, NY*), to the lower reaches of the estuary into waters at the fringe of the salt wedge (*Poughkeepsie, Newburgh, NY*).

During this same time span, the mussel had expanded its Great Lakes range to include most of the St. Lawrence River (*Cape Vincent and Alexandria Bay, NY*); all of the western, southern and eastern shores of Lake Ontario and some locations on that lake's northern shore, most of Saginaw Bay (*Bay City, M*); isolated locations on Lake Huron's eastern shore (*Georgian Bay and the North Channel*; all of the southern half of Lake Michigan (*Manistee, Grand Haven and South Haven, MI; Chicago, IL; Racine, Manitowoc, Green Bay, Milwaukee, WI*); and the northeastern shore of Lake Michigan (*Charlevoix, MI*). Multiple sightings were reported on the Chicago, Des Plaines, and Calumet Rivers and the Chicago Sanitary and Shipping Canal, all in Illinois.

The first sightings in Canadian inland waters were in Balsam, Big Bald, and Rice Lakes, in the Kawartha Lakes chain, and in Lake Simcoe, which are connected to the Great Lakes via the Trent-Severn canal system.

Sightings were confirmed in three of New York's Finger Lakes, (*Seneca and Cayuga, most likely due to canal connections to Lake Ontario or by overland transport by trailered boats, and Conesus, most likely by trailered boats*).

An additional non-Great Lakes Basin was in the headwaters of the Susquehanna River near Johnson City, NY, opening a route for the mussels to travel into Pennsylvania and the Chesapeake basin (but no sightings emerged from the lower reaches of the river).

1992

By July 1992, the mussel had slipped the confines of the Great Lakes Basin, this

time in Illinois, traveling from the Chicago Sanitary and Shipping Canal into the Illinois River, and had reached that river's confluence with the Mississippi River at Alton, IL. The mussel then proceeded upstream in the Mississippi (most likely by means of commercial barge traffic) into southern Minnesota and downstream to the confluence of the Mississippi and the Ohio River. From there, the mussels were transported up the Ohio to the area of the Indiana, Ohio, Kentucky junction. The mussel entered the Tennessee River via the Ohio and moved rapidly across the western tip of Kentucky, into and across western Tennessee, across the northern most reaches of Alabama, and back into Tennessee. Sightings were also being reported in the Cumberland River from the Tennessee River to Nashville.

By the end of 1992, the mussel's range had expanded up the Mississippi to St. Paul, MN, and downstream to Vicksburg, MS. Sightings were confirmed upstream in the Ohio River to a point near Hannibal, OH, and the mussel had added two more rivers to its range, Kanawha River, near Winfield, WV, and the Arkansas, with sightings in Little Rock, AR and western Arkansas.

The mussel continued its spread around the Great Lakes, as well, turning up along more of the northwestern shore of Lake Ontario, the east and west central shores of Lake Michigan, Sault Ste. Marie, and eastern Lake Superior (*Gargantua*, ONT).

1993

By September 1993, a sighting of mussels in White Star Park Quarry (Gibsonburg, OH) appeared to be strong evidence of transmittal by recreational boats or anglers, since the quarry lake has no direct water connections to any infested waters.

The mussel had also shown up in the Vermont waters of southeastern Lake Champlain. A direct canal connection to the Hudson River is the suspected transmittal vector in this case.

The mussel continued its Great Lakes Basin range expansion along the north shore of Lake Ontario, the eastern shore of Lake Huron, and Georgian Bay. It also colonized the Rideau Canal system which joins the Ottawa River with the eastern end of Lake Ontario. To date, all Canadian sightings of the mussel have been within the Great Lakes-St. Lawrence Drainage Basin.

The mussel had filled in much of its range throughout the entire length of the Illinois River; in the Upper Mississippi from Dubuque to St. Paul; the Lower Mississippi in a number of discrete locations as far downstream as Lettsworth, Baton Rouge, and New Orleans; the Atchafalaya River near New Orleans (Berwick Bayou, LA); the Tennessee River upstream past Chattanooga to Lenoir City; and the Arkansas River as far upstream (west) as Cowlington and Gore, OK.

Case Study: The Saga of Barge EMT-211B¹

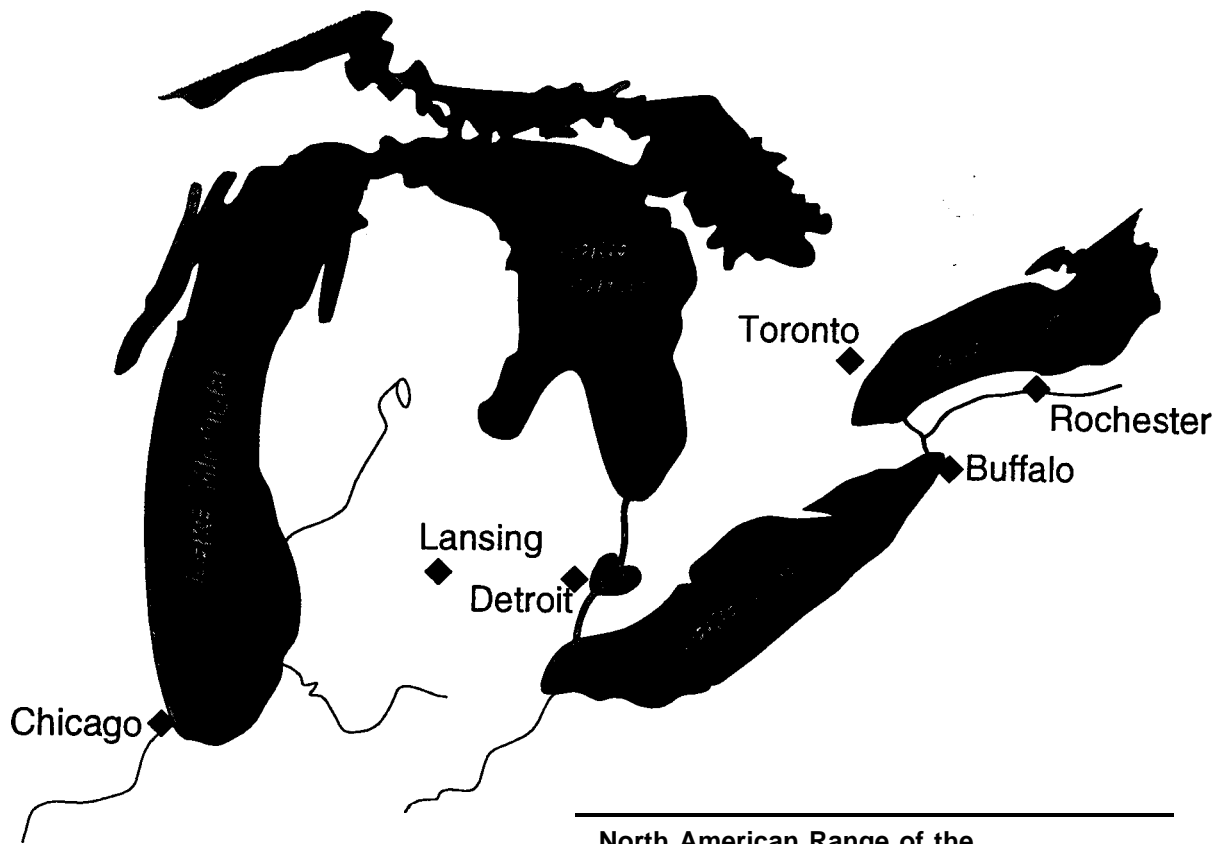
A look at a real-life example of human-influenced dispersal can help to shed light on why the zebra mussel has spread so dramatically in North America. In April 1992, barge EMT-211B was dry-docked in Hartford, Illinois. More than 1,000 live zebra mussels were found on the barge's hull. Randomly distributed clumps of mussels were attached to weld seams on the sides and bottom of the hull. Clump sizes along the side bumper plate ranged from 8 to 34 individuals; clumps from the underside of the hull contained 66 to 96 individual mussels.

The mean shell length of 100 randomly chosen zebra mussels from several clumps on the hull was measured to the nearest 0.1 mm with a dial caliper. The mean shell length was 17.3 mm (standard deviation - 1.6); minimum and maximum lengths were 11.6 and 21.1 mm, respectively. McMahon reported zebra mussel growth rates of 1.0 to 1.6 cm/year in slow and fast growing populations, respectively.² Based on such growth rates, it was estimated that the mussels on the barge were approximately one year old. Working on the assumption of mussel age, and using information provided by the barge's owner, on the barge's movement, it was found that the barge was in the Illinois River between February and May of 1991. It is likely that mussel attachment took place in that river during the early spring or summer of 1991.

If we assume that the mussels attached to the barge hull in or around Spring Valley, IL, in May 1991, the mussels could have been transported an approximate total distance of 15,884 km before the barge was dry-docked. Areas transmitted by the barge during that time period included sections of the upper Mississippi River (as far north as Winona, MN), the lower Mississippi (to Louisiana and Mississippi), and throughout the Illinois River. As there was a potential for mussels to be dislodged from the hull during barge transit, locking and fleeting, and since mussels on the hull could potentially be spawning during the latter part of their journey, the potential for long-distance transport and dispersal of zebra mussels by commercial barge traffic can be seen to be considerable.

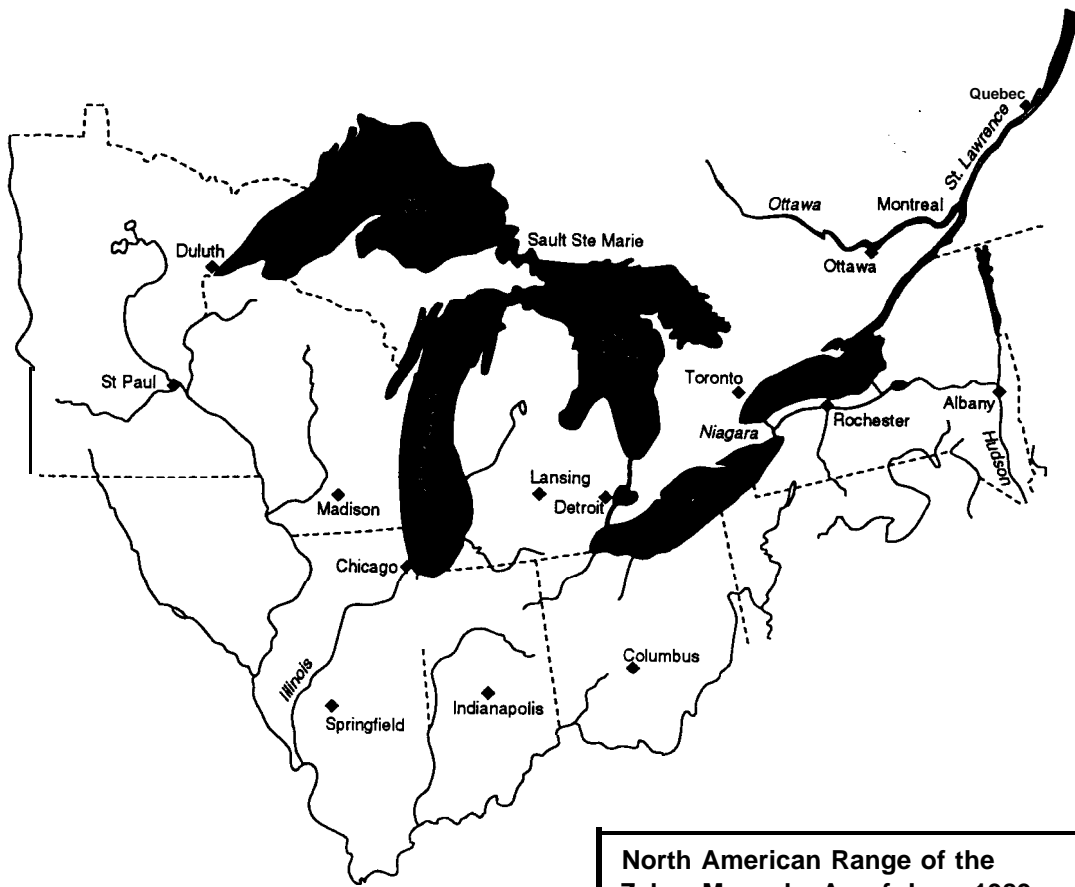
1 Source: Keevin, T., R. Yarbrough and A. Miller. 1990. U.S. Army Corps of Engineers, St. Louis District and Waterways Experiment Station.

2 McMahon, R.F. 1990. *The Zebra Mussel: U.S Utility Implications*. EPRI GS-6995, Electric Power Research Institute, Palo Alto, CA, pp. 1-70.



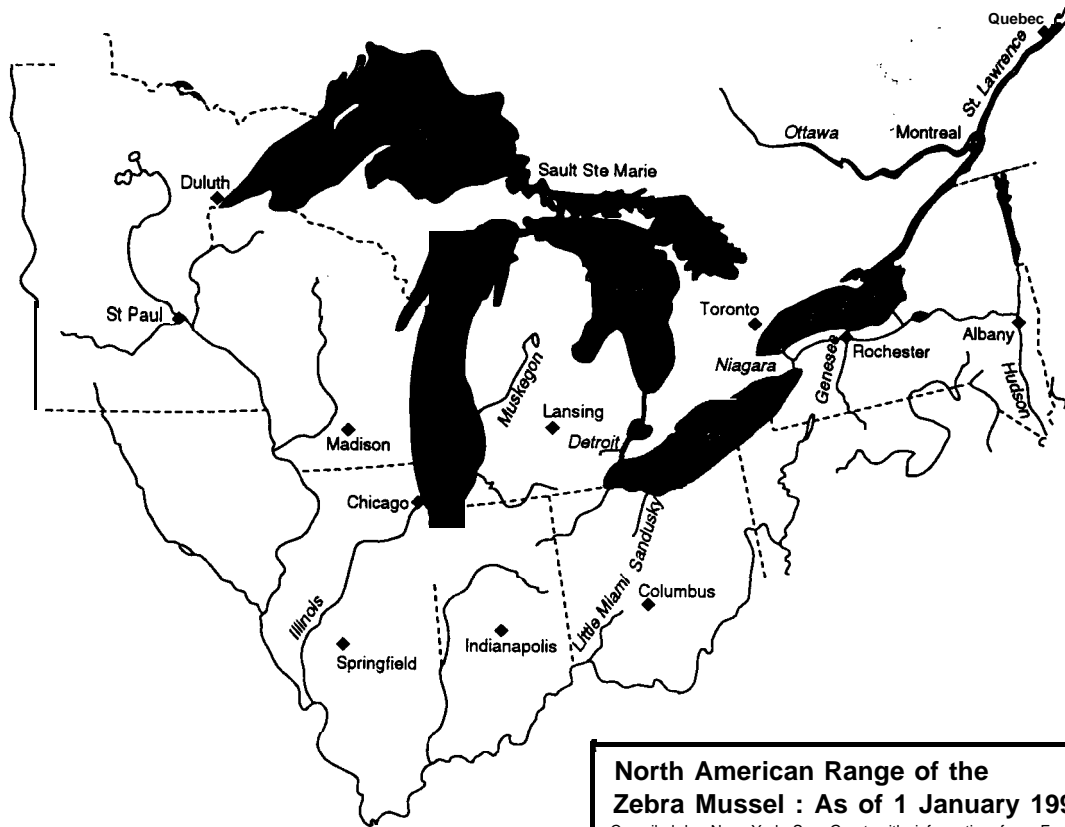
**North American Range of the
Zebra Mussel : As of - June 1988**

Compiled by New York Sea Grant with information from Empire State Electric Energy Research Corporation, Fisheries and Oceans Canada Great Lakes Sea Grant Network, Illinois Natural History Survey, Ontario Hydro, Ontario Ministry of Natural Resources, Tennessee Valley Authority, US Army Corps of Engineers, US Fish & Wildlife Service, and utilities and others throughout North America.
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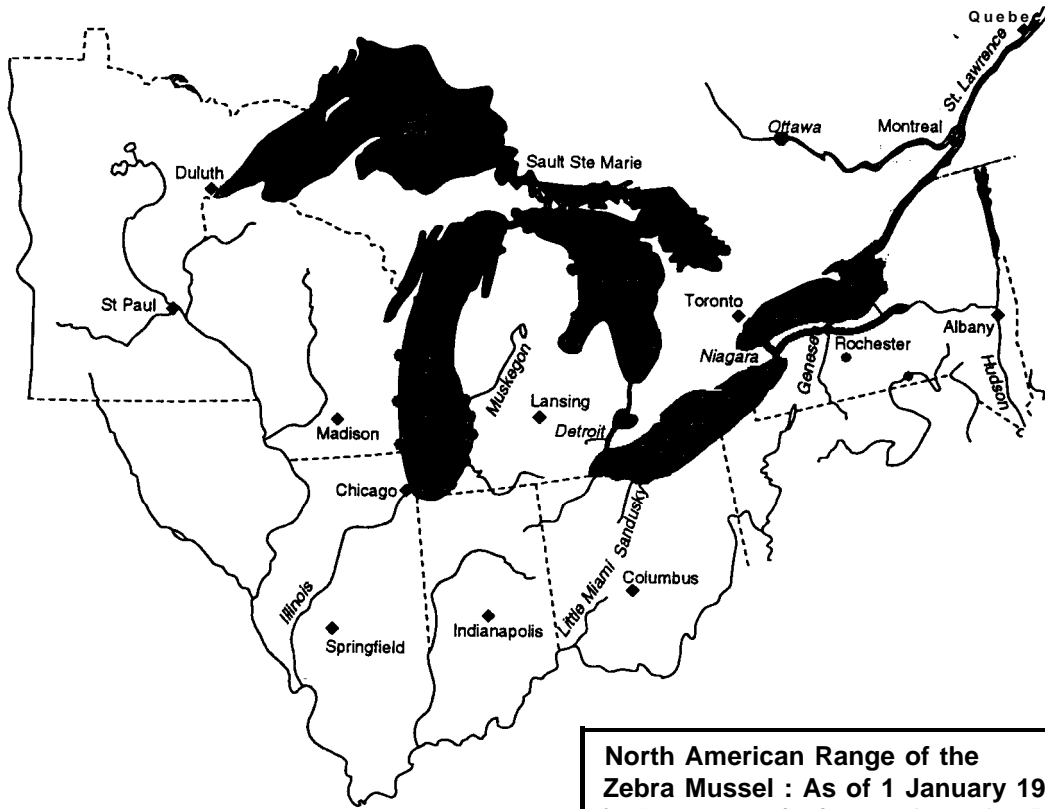


**North American Range of the
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North American Range of the Zebra Mussel : As of 1 January 1990
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**North American Range of the
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